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Analysis of Secular Change and a Novel Method of Stature Estimation Utilizing Modern Skeletal Collections

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by

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Under the Direction of Frank L. Williams

ABSTRACT

Reconstructing stature is at the core of providing information on unidentified human remains. This research shows that there are significant differences between modern populations and those used to create the most common stature estimation formulae. New formulae for the femur and fibula in males and females were created to provide accurate estimates for modern forensic cases. Additionally, a novel measurement of the femur is shown to be moderately correlated with stature and stature estimation formulae for this measurement are included.

INDEX WORDS: Forensic anthropology, Stature estimation, Femur, Fibula

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DEDICATION

To the people who believed that I could succeed. Thank you.

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1 INTRODUCTION

The human skeleton can provide a great deal of information regarding the living individual. Since skeletal material is living tissue, it changes over time. These changes record some of the history of the individual, which can be “read” and interpreted by those with the appropriate training. Forensic anthropologists are specially trained biological (physical) anthropologists who collect skeletal information and use it in conjunction with law enforcement or the courts.

Stature is one of four major characteristics that forensic anthropologists are generally called on to reconstruct when modern fully or partially skeletonized human remains are discovered (Pickering and Bachman 2009; Sauer 1992). The biological profile, which includes age at death, sex, and living stature are assessed based on scientifically determined standards (Dirkmaat et al. 2008; Sauer 1992). Typically the biological profile is compared with missing persons reports for closely matching individuals in order to create a manageable sample, which is then used to work towards a positive identification (Sauer 1992).

Age at death can be estimated through various methods. Dental development can provide an age estimate through the late teens when permanent dentition is fully erupted and root development is complete, and skeletal growth and epiphyseal closure is useful until about the age of 18 (Franklin 2010:2-3). Adults can be aged by changes in the Os coxae, the auricular surface, the pubic symphysis, and fourth sternal rib ends, as well as the closure of the cranial sutures (Franklin 2010:3-4).

As with age estimation, sex determination can be completed by analyzing several different bones. The morphology of the cranium and the pelvis hold the most variation between males and females (İşcan 2005:107). Aside from visual inspection, geometric morphometrics allows landmarks on the pelvis to be analyzed in the computer to provide up to a 93.4% accuracy (Gonzalez, Bernal, and Perez 2009:71). Measurements of the humeral head can provide accuracy of up to 95.5% according to one study on a Guatemalan sample (Frutos 2004:155).

Additionally, the culturally perceived ethnic background of the individual is part of the assessment (Sauer 1992). Ethnic background, often denoted as "race" is included in missing persons reports, and is generally requested by law enforcement (Sauer 1992).

In addition to creating the biological profile, forensic anthropologists may be called on to testify in civil or criminal cases and present their findings or act as expert witnesses (Dirkmaat et al. 2008:35; Pickering and Bachman 2009:171) . Scientific evidence may assist law enforcement. By determining the fate of the manner of death of the deceased, forensic anthropologists may be able to bring closure for that person's family and friends.

The expansion of forensic anthropological methods throughout the world means that they are used in areas with populations that are not represented in the groups used to create the most common stature estimation formulae. Due to differences in diet, nutrition, and other environmental factors, these individuals may have different bodily proportions than those in the United States, and thus stature estimation may not be accurate (Ruff 2002).

Stature estimation is utilized in a similar fashion as with crime scene investigation (and mass grave locations are treated as crime scenes). Stature estimation is used to narrow down the possible identities of victims. In regards to human rights work, Western forensic anthropologists have been called on to aid in the excavation of mass graves and identification of victims in foreign countries, and need to be aware of the population differences noted above (Hunter and Cox 2005).

In Bosnia, more than 8,400 individuals were missing from one region alone, and in Herzegovina 2,000 were missing, following the 1992-1995 war in the former Yugoslavia (Ferllini 2007:149, 156). Forensic anthropological analyses may bring to light human rights abuses, like the ethnic cleansing in the former Yugoslavia. Analyses completed by forensic anthropologists may again be utilized in court to bring those who perpetrated human rights abuses to justice. Unlike criminal trials in the United States, however, human rights cases may be filed on behalf of, or in the names of the deceased (Kimmerle et al. 2008).

1.1 Purpose of the Study

The purpose of this study is twofold. First, it aims to determine whether evidence of a secular change can be identified between the classic reference population used in stature estimation and more modern skeletal assemblages. If this is indeed accomplished, the second aim is to develop new regression formulae that take these secular changes into account. It therefore aims to refine methodologies for forensic stature estimation in ways that more accurately account for recent patterns of skeletal growth in the United States. Calls for improved analytical methods in forensic anthropology have been voiced for at least 20 years, emphasizing the need to use updated samples that represent modern populations (Dirkmaat et al. 2008). Long term changes in stature mean that the population today is not the same as earlier populations in the United States (Dirkmaat et al. 2008). A secular trend is any change that takes place over successive generations. The secular change in stature is said to be linked to socioeconomic circumstances (Webb et al. 2008:228). Affluence and health status of populations are major influences on stature (Webb et al. 2008:228).

Two studies of secular change in the United States are notable and useful to frame the research that follows. Richard Steckel (Komlos 1994) utilizes data from a number of height studies, including the slave and Ohio Guardsmen research referenced above, to show trends in stature between 1710 and 1950. Sources of data in these varied works are also drawn from regular army and city schools (Komlos 1994:154). From the available data, which is limited, there is evidence that stature in the United States has seen a number of fluctuations over time (Komlos 1994:157). The earliest data have a mean of 172.1 cm, only 1.1 cm shorter than that of the mean of a group born in the 1920s (Komlos 1994:157-158). Stature was steady between 172.5 and 173.5 in those born from 1780 through 1830 (Komlos 1994:158). A low at 169 cm was the average reached in the late 1800s (Komlos 1994:158). It is after this point that the secular increase recognized in the twentieth century began (Komlos 1994:158).

Another aspect of stature which is often studied is leg to trunk proportions and upper to lower leg length proportions. These proportions are studied by forensic anthropologists as they are integral to the creation and use of stature estimation formulae. Lee Meadows Jantz and R. L. Jantz (1999) examined secular change in long bone lengths in relation to stature over the period of 1880 to 1970. Though the data presented is primarily that of bone lengths, the analysis is on how long bone lengths are related to stature and how proportions of the bones have changed (Jantz and Jantz 1999). According to Jantz and Jantz (1999:65), there was a secular increase in stature that is expressed in the lower limbs as a relative lengthening in relation to the trunk. Another interesting finding is that at some points there was a difference in the amount of change between men and women where the increases in male stature was about twice what it was in females (Jantz and Jantz 1999:65).

There are two types of change in stature that may occur, isometric and allometric (Jantz and Jantz 1999). Isometric change is characterized by no alteration in the proportion of a body part to the overall stature (Benton and Harper 1997). Allometric change may be categorized as either positive or negative. If positive allometry is present, the body part in question is longer than it would be if the change were isometric. If the body part is shorter than it would have been if isometric change were occurring, then the allometric change is categorized as negative.

If there is a secular change, but the change is isometric, then previous regression formulae would still produce relatively accurate results. The slope of the regression equation would be approximately the same, but the distribution of the data points would be shifted. For example, if individuals increased in stature, and their limbs also increased at similar rates, the data points would be skewed up and to the right on a regression line, but still cluster around the line.

Any allometric change would result in regression models that are no longer accurate. If the allometric change in the population was overwhelmingly positive, then the regression formulae would predict a living stature greater than the actual stature. The opposite would occur with negative allometric change, resulting in shorter than expected estimates.

Jantz and Jantz (1999) also note that increased error may be introduced when stature estimation formulae that use multiple long bones are utilized when the rate of change between bones is not the same. Analysis of the change showed that upper limb bones are not changing at the same rate as the lower limb bones, so formulae that rely on both upper and lower limb bones are the ones that are most affected (Jantz and Jantz 1999).

Another motivation for this research is that forensic anthropologists are often confronted with fragmentary remains (Simmons et al. 1990:628). The fact that long limb bones are strongly correlated with stature suggests parts of each long bone should also be positively correlated with stature (Simmons et al. 1990:628). Though this is the case, previous tests of certain long bone segments show that there are often problems locating landmarks on the bones used for measuring (Simmons et al. 1990:628).

The first phase of this study assesses secular change in the United States between the early 1800s and the late 1900s. This will be accomplished by comparing modern samples from large and well-documented human skeletal assemblages to a portion of the data used to create the older stature estimation formulae that are still in general use today. A significant change in stature or proportions of the long bones reveals the need to create updated stature estimation formulae.

As an extension of this basic work, additional methods for addressing situations such as incomplete skeletal elements must be analyzed. The femur is the most robust bone in the body and is protected by soft tissue, and as such is most likely to survive in cases such as air crashes (Simmons et al 1990:629). Even so, fragmentary remains are found and the femur being most highly correlated with stature is a good starting point for analysis.

1.2 Limitations

Adams and Byrd (2002) tested interobserver error in postcranial measurements in a group of 68 anthropologists, odontologists, and pathologists with osteological experience ranging from less than one to 25 years. The research did not include standard length measurements, such as maximum length of the femur however, citing their documentation and simplicity of taking them. All obviously erroneous measurements, transpositions, and anything outside of five standard deviations from the median removed from the data set. With these data, the error rates for standard measurements were generally less than three percent. The authors explained that the measurements were not taken in a lab environment, which may explain some of the errors, but 57% of individuals with a year or less experience, and 24% of those with over ten years of experience made at least one mistake (Adams and Byrd 2002).

1.3 Summary

Stature is part of the biological profile created for unidentified skeletal material in forensic and human rights cases. Stature change has occurred in the United States and new stature estimation formulae may be required. Fragmentary remains, including incomplete bones are often found, requiring special formulae to estimate stature.

This study will examine secular change in stature by comparing a modern collection with an earlier, contrasting collection. Analyses of the regression formulae from both sets of data will be examined to determine if new formulae are required. Finally, a new measurement of the femur will be tested for correlation with stature in an effort to create a method for estimating stature for fragmentary femora.

2 STATURE

2.1 Biological Basis of Stature

The final size and shape of an organism is thought to be the result of external stimuli acting on that organism during development (Bogin 1999:11). There are two different foundations for the study of stature that should be investigated. As with the nurture versus nature debate, genetics and adaptation seem to be important in understanding how individuals and populations grow to be of various statures.

Genetics is one foundation of human growth and development. The genetic pattern of growth is regulated by proteins that are produced by genes (Bogin 1999:329). The endocrine system (itself a product of one's genes) produces testosterone and estradiol in boys and girls respectively (Bogin 1999:330) These hormones, in conjunction with growth hormone in both sexes, cause the adolescent growth spurt (Bogin 1999:330).

Jesper L. Boldsen (Mascie-Taylor and Bogin 1995) used quantitative genetics in researching stature in Danish communities that were involved in a process of the breakdown of reproductive isolation. During a period of nearly 900 years there was little change in stature (Mascie-Taylor and Bogin 1995:83). Not until there was "outbreeding" between Danish communities in the nineteenth century did the population see major increases in stature (Mascie-Taylor and Bogin 1995:87). The only change in these communities was the inclusion of DNA that had not been part of the gene pool before the outbreeding.

There are those who discount the importance of genetics in population studies of stature. James M. Tanner (Komlos 1994:1) writes that most between-group variation comes from "the cumulative nutritional, hygienic, disease, and stress experience of each of the groups".

This idea seems plausible when related to the research suggesting that most groups (not including Asiatic populations) may have the same potential for prepubertal growth (Ulijaszek 2001:46).

If ethnic differences in stature are decreasing, then perhaps the population differences in stature are due to the variation in environmental factors. Perhaps as nutrition levels increase and levels of stressors decrease, research would show that all populations will have relatively similar stature. With so many factors affecting stature to different degrees, it does not seem likely that this type of research is plausible.

However, research on genetics such as that mentioned above cannot be ignored. If introducing new genes into a population results in an increased stature, and the environment has not changed, there is strong evidence of genetic influence (Mascie-Taylor and Bogin 1995). Tanner (Komlos 1994:3) argues that genetics plays a role in the *rate* of stature growth of populations after discounting its role in final adult stature. It seems difficult to separate mechanisms that would control rate of growth from potential of that growth.

Adaptation is another level at which stature is affected according to Boldsen (Mascie-Taylor and Bogin 1995). It is at this level that environmental interaction causes organisms to change in response to external stimuli. One type of adaptation, plasticity, works during the lifetime of an individual, and is also described by Boldsen (Mascie-Taylor and Bogin 1995:76). Bogin (1999:35), used the work of Franz Boas to elucidate this factor. The American-born children of immigrants had physical characteristics that were more like other American-born citizens than their parents (Bogin 1999:35). It was believed that differing diets and the health care available to the children were the cause of these plastic changes (Bogin 1999:35). Plastic change is the level at which most of the following factors operate.

Many factors are wide-ranging and work on the population at large. Though they do not necessarily affect everyone in the exact same way or to the same degree, aspects such as nutrition, disease, and environment, will touch the lives of many, if not all, of the members of a group. In sub-optimal conditions, some of these factors act as stressors on the organisms. Income as a factor can be confounding in that it does not always have the same effect in all situations, and will be mentioned in conjunction with nutrition.

Not only important to growth, nutrition is also used for body maintenance and for physical activity, notes Floud (Komlos 1994:11). He explains that if nutritional needs are not met, then growth may be retarded or may stop completely. A number of real world and experimental studies show how nutrition affects stature. In one study begun in the 1960s, two groups of Guatemalan villagers were given either an experimental supplement or a placebo (Bogin 1999:277). The findings showed that supplementing children up to the age of seven resulted in an increase in stature compared to those that received the placebo (Bogin 1999:277).

Research has been done on a number of specific foods that have significant effects on stature. The impact of many generations of milk intake, or even the introduction of milk into the diet has been studied in many cultures (Bogin 1999). The introduction of milk to Japan after World War II and supplementation in Scotland produced stature increases (Bogin 1999:278). African pastoralists whose diets contain a lot of milk tend to be taller than their agricultural neighbors that have diets devoid of milk (Bogin 1999:278).

Even though a number of studies on supplementation focus on people with lower economic status, it is not possible to always equate a lack of nutrition (and short physical stature) with poverty. Joel Mokyr and Cormac Ó Gráda (Komlos 1994) examined how before the Great Famine, the Irish, who had little more than the basics of life, were still able to flourish. The diet of potatoes, that was enhanced with the addition of fish and milk, helped to stave off disease (Komlos 1994:57). The potato, being thought to cause leprosy, was initially shunned by much of Europe (Foster and Cordell 1992:5) In spite of this, the potato became the staple crop of Ireland soon after its arrival in the Old World (Foster and Cordell 1992:12). Relative health and adequate nutrition allowed the Irish to grow taller while eating a diet that others chose to avoid (Komlos 1994:57).

Similar trends are shown in a number of countries during the Great Depression. Jialu Wu (Komlos 1994) found that in Pennsylvania during the Great Depression, people were still able to obtain nutritious food and physical well-being did not suffer substantially. Argentina, also affected by the Great Depression, saw a continuous increase in stature throughout the period (Salvatore 2009). These works show that nutrition and income level need to be examined carefully in relation to stature.

Climate affects stature in a number of ways. Body size and shape is directly related to the climate in which the population lives (Bogin 1999:286). This is a fundamental part of mammalian biological adaptation (Bogin 1999:286). In hot climates, there is a need for relatively large body surface area in order to allow for greater cooling through evaporation of sweat (Bogin 1999:287). This can be achieved by having relatively long arms and legs in proportion to the trunk of the body (Bogin 1999:287). This trend is reversed in cold climates, with individuals having relatively larger trunks in proportion to their limbs (Bogin 1999:287).

Weather can have an impact on nutrition, itself a factor in stature, as mentioned above. Combining data from ice cores and tree rings, along with other sources, Richard Steckel (2004) looks at weather change during the Middle Ages. During the period of about 900 to 1300 A.D. the temperatures were warmer than even modern averages (Steckel 2004:217). This meant warmer and longer growing seasons and allowed for a larger area available for cultivation (Steckel 2004:217). These factors led to increased agricultural output (Steckel 2004:217). Better nutrition resulting in an increase in stature led to averages not seen again until the early twentieth century (Steckel 2004:211).

Disease may have a negative effect on stature. Bogin (1999:284) references studies that show intestinal parasites and malaria, in conjunction with undernutrition, have negatively affected stature in Ethiopia and Nepal. Evidence of disease is also drawn from paleopathology. Increased health, inferred by a negative correlation between the incidence of Harris lines and increased stature in a Peruvian population, is a useful example (Cohen and Armelagos 1984:596-597).

Migration can have an effect on growth and development. There are a number of differing scenarios to migration as well. People may move from one country to another, or they may move between rural and urban areas. This means that urbanization may therefore be linked with the process of migration. Komlos (1994) used observed statures of African slaves to describe an increase in stature during the 1700s in relation to three locations. His data suggest that African born slaves did not achieve the same average height as those born in the Caribbean

(Komlos 1994:97). American born slaves of African descent were taller than those born in both locations (Komlos 1994:97). Later, voluntary migrations to the United States also showed differences in stature. Recruits in the Ohio National Guard were measured and that information was kept in the muster rolls, which were studied by Richard H. Steckel and Donald R. Haurin (Komlos 1994). Guardsmen who were born in the United States were on average 0.84 inches taller than those who were foreign-born (Komlos 1994:122).

Migration to another country may also include the move to an urban area. Research by H. L. Shapiro on Japanese immigrants to Hawaii is one example of this used by Bogin (1999:298). The children of Hawaiian-born Japanese migrants were taller than their parents and Japanese people who still lived in the villages that their parents came from back in Japan (Bogin 1999:298). The improved diet, health care, and socioeconomic status that came with the move to an urban environment were the causes of the increase, in the view of Shapiro (Bogin 1999:298).

This is not to say that urbanization always results in an increase in stature. Children who lived in rural areas in the United States between 1870 and 1920 were taller than those living in urban areas (Bogin 1999:298-299). This overlaps the period studied by Salvatore (2009) in Argentina referenced above where the opposite was the case. The gains in Argentina were attributed to urbanism in addition to a better diet (Salvatore 2009).

J. Patrick Gray and Linda D. Wolfe (2002) explored the stress hypothesis in explaining the distribution of stature across the globe. Unlike some stressors, such as malnutrition, which would result in decreased stature, this area of research focuses on events that seem to cause an increase in adult stature (Gray and Wolfe 2002). Some of the types of acute stress, which individuals would go through during infancy, that were identified were piercing, scarification, vaccination, circumcision, and lack of physical contact with the mother or a midwife (Gray and Wolfe 2002:211-212).

In the light of previously discussed factors, the data that are referenced are less than compelling. The data come from Yemenite children born in hospitals where they are separated from mothers and those born at home who stayed with their mothers continually (Gray and Wolfe 2002:212-213). Those born at hospitals weighed more each of the first three years compared to those born at home (Gray and Wolfe 2002:213). The data do not however include adult stature of the children in the study (Gray and Wolfe 2002:213). Without data on adult stature present, this could simply be an example of an increased growth velocity not affecting final adult stature. The research also does not provide any evidence that females are affected by physical stress with increased stature, though males are influenced (Gray and Wolfe 2002:213). The authors note that this result does not support the those of similar increases in males and in females found in previous research (Gray and Wolfe 2002:213).

Tanner (Komlos 1994:1) also informs readers that individuals are not taken into account in anthropometrics, and the population is the unit of study. Forensic anthropologists draw their data from the population level, but most work in the field is performed if not on a single individual, then a group of individuals. If nothing else, these factors in individual stature are intriguing in how they might create outliers in the population.

An individual's stature "depends more on his or her parent's heights than anything else" is the view on genetics of Tanner (Komlos 1994:1). Boldsen (Mascie-Taylor and Bogin 1995:79) includes conclusions drawn with Mascie-Taylor about a "maternal effect". In general, if there are large differences between the heights of the mother and father, children's height will be more dependent on the mother's stature (Mascie-Taylor and Bogin 1995:79). The effect is opposite what may be assumed from the name of the effect, with short mothers having taller children and tall mothers having shorter children (Mascie-Taylor and Bogin 1995:79). This is suggestive of stature being highly influenced by the genes of the parents.

Modern medicine has provided a way for children shorter than average to attain greater adult stature. Growth hormone is used by physicians to treat idiopathic short stature (Blizzard 1999; Silvers, et al. 2010). This procedure is not something that is done very often and does not affect the whole population, but is a potential treatment for 500,000 children in the United States (Silvers, et al. 2010:468). A review of a study of 80 children who received growth hormone revealed that about half gained less than 5 cm over their predicted adult stature, though others gained over 10 cm (Blizzard 1999:23). While some of these individuals as adults would still be close to the general trends in stature, it is possible that some individuals may deviate from the trends.

2.2 Methods of Stature Estimation

Research has been completed on a number of methods for estimating stature. T. Dale Stewart (1978) provides a detailed history of stature estimation, from which I will mention a few of the highlights. This history begins with Thomas Dwight in 1894 stating that there is no rule of proportion for estimating stature from the long bones of the legs because some people have short legs and some people have long legs (Stewart 1978:190). Dwight suggested that the anatomical method (measuring all bones that make up stature) should be used unless there was no other choice (Stewart 1978:190).

Next, in 1888, Paul Topinard published on the use of ratios to estimate the stature of the skeleton from the maximum lengths of long bones, to which the constant of 35 mm was added for the living stature (Stewart 1978:194). In either the same year or the one following, Étienne Rollet published his doctoral thesis, and he included tables of his data displaying bone lengths and their corresponding stature (Stewart 1978:195). Léonce Manouvrier did not like the layout of Rollet's tables (Stewart 1978:195). As he was the head of the Anthropology Society of Paris at the time, when he published his own version of Rollet's data, his work became the one that was most utilized (Stewart 1978:195).

Karl Pearson was the first to use regression theory in 1899, analyzing the data collected by Rollet (Stewart 1978:198). Pearson, diverging from the practice of using bicondylar length by Manouvrier, used solely maximum length of the femur (Stewart 1978:198).

Trotter and Gleser (1952) cite a number of early stature estimation examples that are precursors to their own work. Many reference books, including laboratory and field manuals, even those published recently, include the formulae or stature tables created by Trotter and Gleser (Bass 1995; Buikstra and Ubelaker 1994; Burns 1999). Trotter and Gleser (1952) collected data from the Terry collection, and from U.S. war dead. They created regression formulae based on upper and lower long bone lengths of men and women which were divided by socially attributed racial categories.

Georges Fully, whose most memorable work is likely the "Fully" anatomical method of stature estimation, had created estimation formula from long bones in 1956 (Raxter, Auerbach, and Ruff 2006). Unfortunately Fully did not give explicit directions on how to take the measurements needed, but recent work has been completed based on the original method, with results that correlate to stature at 0.96 (Raxter, Auerbach, and Ruff 2006:379).

Other methods of stature reconstruction have been researched that do not require the use of long bones, and have been tested again on and off. Giroux and Westcott (2008) tested the correlation between stature and sacral height, hip height, and femoral head diameter, obtaining data from 247 individuals in the FDB at the University of Tennessee. These measurements do seem to correlate significantly with stature. Only sacral height in white females had a p value of greater than 0.05. The authors do find that the confidence interval based on the mean and standard deviation falls outside of the 95% confidence interval, suggesting that there is not enough accuracy for use in identifying individuals (Giroux and Wescott 2008:68). Giroux and Westcott (2008) also note the ability to use metacarpals, metatarsals, and ankle bones in stature estimation, all of which end up being more accurate than sacral height.

Another aspect of Thomas Dwight's work around the turn of the 20th century used the sternum and the spine for respective stature estimation formulae (Stewart 1978:191-192). The sternal method was found to be useless, because sternum length was so variable compared to stature (Stewart 1978:191). One recent study supports those results with a correlation of only 0.329 (Marinho et al. 2012). Yet another study found the correlation in their samples to be quite high at 0.659, so the measurement is likely to be studied further (Menezes et al. 2011:243). Dwight had more success with the spinal method, though a large proportion of his sample was over the age of 60 and he did not document how he measured the "body length" with which he correlated the length of the spine (Stewart 1978:191-192).

The Steele method, developed by D. Gentry Steele (1970), can be used when intact long bones are not discovered. Once measurements have been made, they can be translated into stature estimates indirectly or directly. In Steele's indirect method, measurements of landmarks on fragmentary long bones are used to estimate their maximum length, which are then be put into the regression formulas for stature. Steele's direct method derived estimates from the fragments themselves, bypassing the extra step of using the Trotter and Gleser equations.

Stature estimation from fragmentary remains through Steele's method has been re-viewed by a number of scientists as well. Standard and clearly defined measurements were used by Simmons and colleagues (1990), and subsequently, the stature estimates obtained were more accurate. Wright and Vásquez (2003) found that greater reliance on articular land-marks was one way to improve accuracy of the measurements.

Steele (1970) originally wrote that the indirect method of stature estimation from frag-mentary long bones provided a more accurate result than the direct method. Subsequent anal-yses by Wright and Vásquez (2003) and Bidmos (2009) arrive at the conclusion that the direct method is not only more accurate, but is also less complicated. The indirect method involves two sets of equations. This can take extra time and the extra step is another point where hu-man error can be introduced. When following the two step indirect method, the standard er-rors of estimation apply to both regressions, and the final standard error is quite large com-pared to that of the direct method. A larger standard of error suggests a less accurate estimate.

The proximal femoral breadth, measured along the axis of the femoral neck, has been tested on skeletal populations of known stature, and has been shown to have a high correlation with the length of the femur (Simmons et. al. 1990). Length of the femur is in turn highly correlated with living stature. A measurement that is slightly modified, but simpler to collect, was tested with similar results by Bidmos (2008a, b) in skeletal populations which lack living stature information.

Bidmos (2008a:296) collected data from a sample of 100 indigenous South Africans from the Raymond A. Dart collection, which is housed at the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. The individuals were from a number of tribes (Bidmos 2008a:294). The majority of the samples were from four tribes, but were lumped together as they showed no statistically significant intertribal differences (Bidmos 2008a:294). It was found that the correlation of the upper breadth of the femur to be 0.608 to total skeletal height, and 0.653 to the maximum femur length in males (Bidmos 2008a:296). Females in the study had a higher correlation at 0.785 to total skeletal height and 0.799 to maximum length of femur (Bidmos 2008a:296). Total skeletal height was used in the study since no living stature information was available, determined by using an updated version of the Fully method (Bidmos 2008a:293).

Bidmos (2008b) completed similar research on a sample of consisting of South Africans of European descent. The individuals were descendants of migrants from many European countries, including the Netherlands, the U.K., France, and Germany (Bidmos 2008b:1044). As with Bidmos's study on indigenous South Africans, this sample comes from the Raymond A. Dart Collection (Bidmos 2008a, 2008b). Correlations for the European males were similar to those for Indigenous South African males, at 0.661 between upper breadth of the femur and total skeletal height, and 0.610 between upper breadth of the femur and maximum length of the femur (Bidmos 2008b:1044). Correlations with these measurements in females were much lower than with the previous study. Upper breadth of the femur was correlated with total skeletal height at only 0.562 and with maximum length of the femur at 0.623 (Bidmos 2008b:1044).

After the creation of the FDB, researchers have been able to access modern data, and there have been some new assessments in the past two decades. Richard Jantz (1992) used the data in the FDB to test the reliability of Trotter and Gleser's equations, and created new formulae for females based on the data therein. Jantz's (1992:1232) study involved splitting the modern sample by race, which reduced the number of tibiae to 19 in the "black" category, and femora to 26. Using samples as small as those in these analyses may call into question the reliability of the stature estimation formulae produced. Stephen Ousley (1995) also created a limited number of updated formulae when testing the use of measured stature versus self-reported stature.

Occasionally, researchers complete analyses on established methods in order to determine the most accurate version that should be used. In an effort to understand which anatomical method is the most accurate, Heli Maijanen (2009) tested eight procedures on a sample of males from the W. M. Bass Donated Skeletal Collection. Included were the Fully method and the Raxter and colleagues revised Fully method mentioned above (Maijanen 2009:746). A modified Fully method in which measurements of the vertebrae are taken at the posterior midline had the highest correlation with living stature at 0.938 (Maijanen 2009:750).

New methods of stature estimation have been developed in an effort to achieve accurate results from as much as a full skeleton to as little as a fragment of a single bone. The upper breadth of the femur is one of the most recent methods that has been tested that has applicability in modern forensic and human rights work. By studying this method of stature estimation and testing on modern American populations, previous work is being verified and extended to a new population.

3 EXPERIMENT

3.1 Materials

Data collection for stature estimation formulae can be problematic. Hauser and colleauges (2005:186) reveal that “there are no studies that permit the establishment of body length when alive for the contemporary population on the basis of measurements taken from a skeleton” that fully satisfy forensic scientists.

Some attempts have been made to collect data from living individuals through methods such as radiography (Hasegawa et al. 2009). Even with dual-energy X-ray absorptiometry, a special form of scanning that limits magnification of less than 1%, measurements are still not taken directly from the bones (Hasegawa et al. 2009:264). Other researchers suggest that even with quality X-rays, caution should be taken, and anthropometry using well-documented skeletons is still the best choice for data collection (İşcan 2005:107).

The first criterion for data collection at the two institutions was age. The lower limit was set at age 18 at time of death, with no upper limit. Growth of the long bones halts as humans reach maturation, and long bone lengths to not change significantly throughout life (Galloway 1988). Although not all long bones stop growing at the age of 18, Trotter and Gleser (1952:469) bring to light that the amount of increase in stature after the age of 18 is not significant.

Stature estimation formulae have only “historical value” when created from older skeletal collections which do not take secular changes into account (Hauser et al. 2005:186). Calculated stature does not express how tall the individual was while alive, but is an estimate of how tall the person may have been if they belonged to the population used to establish that formula (Hauser et al. 2005:188). In an effort to create formulae that would be most like populations alive in the United States today, sites for research were selected which hold the largest number of contemporary skeletal remains.

Samples for this study come from two locations as shown in Table 3.1. The first collection is located at the Laboratory of Human Osteology in the Maxwell Museum of Anthropology. The museum is located at the University of New Mexico in Albuquerque. All of the samples are part of the Documented Skeletal Collection, which consists of remains that were donated by the individual or their family, or by the Office of the Medical Investigator when no next of kin was found (University of New Mexico, 2003). As of 2003, the museum curates the donated remains of 235 individuals in the Documented Skeletal Collection (University of New Mexico, 2003). Of these, six females and 23 males met the criteria used in selection of the samples.

Table 3.1 Sample Sizes

Source	Number of Males	Number of Females
University of New Mexico	23	6
University of Tennessee	138	62
Combined Modern Samples	161	68
Terry Collection	1585	493

A larger sample was drawn from the W. M. Bass Donated Skeletal Collection at the University of Tennessee in Knoxville. The Bass Collection consists of around 900 individuals, with around two-thirds having been donated by the individuals or their families. The remaining individuals are medical examiner donations. From the Bass Collection, 62 females and 138 males were assessed.

The Robert J. Terry Anatomical Skeletal Collection, currently housed at the Smithsonian National Museum of Natural History in Washington D.C. provided Mildred Trotter and Goldine

C. Gleser with the materials to create the regression formulae for stature estimation of Americans in their 1952 work. The Terry collection was originally a medical school collection used for scientific study, and most of the individuals have documented age, sex, and ethnic background (Trotter and Gleser 1952 468). These formula are still in use today, but do not reflect the secular increase in stature found in twentieth century America.

Dr. Frank Williams of Georgia State University provided the data from the Terry Collection. Individuals missing data for at least one long bone of the lower limbs were removed from the sample because there was no way to determine what sort, if any, damage was present on those bones that might affect stature.

Long bone lengths, femoral condyle breadth, and tibial condyle breadths were taken with standard osteometric boards, which were provided by the institutions where research was completed. Upper breadth of the femur and all diameters were measured with digital calipers. Measurements taken with the osteometric boards were rounded to the nearest centimeter, while measurements with calipers were taken to the hundredth of a millimeter. IBM SPSS was utilized for all of the statistical analyses of the data and production of graphs. At the University of New Mexico, data were entered directly into Microsoft Access. During the first trip to the University of Tennessee, data were entered into a spreadsheet in Microsoft Excel. A printed spreadsheet was used to enter data during the second trip to the University of Tennessee. These data were then entered into SPSS.

3.2 Methods

Mathematical approaches vary in their reliability with the selection of the bones that are used to make the estimations. The researchers who create the formulae choose the elements most highly correlated with stature in order to get the most accurate estimation of living height (Jantz and Jantz 1999; Trotter and Gleser 1952). The ability to use a specific formula depends on the skeletal elements that are present. Upper limbs are less correlated with stature in general than lower limbs, so if only upper limb bones are discovered, the estimates are not going to be as accurate as they could be with lower limbs (Jantz and Jantz 1999; Trotter and Gleser 1952). The profusion of regression formulae for different bones is a benefit, since it allows for stature estimation when limited skeletal remains are present.

Trotter and Gleser (1952:471) advise that one individual should take all measurements of a specific variable in order to reduce error. The reduction in correlation between variables seen may decrease if the population being examined is large enough (Trotter and Gleser 1952:471). As the population currently being assessed is relatively small compared to the numbers being examined by Trotter and Gleser, all measurements were taken by the author.

In Europe, using bone material that has been removed from cadavers has been criticized, and therefore indirect methods have been used to collect data, such as the use of X-rays (Hauser et al. 2005:189). However, not using direct skeletal measurements results in major error (Hauser et al. 2005:189). All measurements for the current research were taken from complete skeletons in donated collections in the United States.

Measurements were taken from both left and right sides, though for this analysis only the right skeletal elements were utilized. Researchers will often substitute the other bone in a pair being used for analysis if the preferred element is damaged or missing (Dayal 2008). For this analysis, any skeletons that had damaged long limb bones of the lower limbs were left out of the analysis. Individuals missing long bones of the lower limbs were also excluded as the condition of the missing elements could not be assessed.

Measurements described by Trotter and Gleser (1952) were utilized for most of the data collection. These standard measurements were taken:

Femur: Bicondylar length. With both condyles touching the vertical stationary end of the osteometric board, and the anterior surface facing up, the foot of the board was moved to touch the head of the femur.

Femur: Maximum length. With the medial condyle touching the vertical stationary end of the osteometric board, and the anterior surface facing up, the foot of the board was moved to touch the head of the femur. The head of the femur was moved up and down and side to side to determine the maximum length.

Fibula: Maximum length. With the head of the bone touching the vertical stationary end of the osteometric board, the foot of the board was moved to touch the distal end of the bone. The distal end of the bone was moved up and down and side to side to determine maximum length.

Unfortunately, the tibia measurements used by Trotter and Gleser are believed to be too short for the method described, which includes the medial malleolus, so the data is not reliable (Jantz, Hunt, and Meadows 1995). Some of the measurements utilized by Trotter and Gleser were collected by technicians, and accurate analyses of the data may not be possible. Measurements for the tibia were not included in this analysis.

Additionally, midshaft diameters were taken from femora and fibulae. Transverse (medial-lateral) diameter was measured on the femora. Maximum diameter of the fibula was taken by rotating the bone inside of the calipers to find the greatest diameter.

Upper breadth of the femur, displayed in Figure 3.1, was taken from the most superior point of the fovea capitis to the inferior aspect of the greater trochanter. This measurement can be taken by one individual. No other steps such as drawing a line through the axis of the neck of the femur are needed.

Photo by Author

Figure 3.1 Upper Breadth of the Femur

Since Trotter and Gleser's work (1952), separate equations have been derived not only for males and females, but for different ancestral or racial groups (Jantz 1992; Ousley 1995). The collection that Trotter and Gleser (1952) included individuals described as "whites" and "negroes". Later assessments included Native Americans, based on skeletal material from archaeological sites (Auerbach and Ruff 2010). In place of a living population, the Fully method was used to estimate living stature, and regression equations created with that information (Auerbach and Ruff 2010). Formulae for Mesoamericans were also created because calculated statures for individuals based on other populations were so large as to be "absurd" (Genoves 1967). This is due to the fact that the Native American group studied was not contemporary with modern Americans, and the Mesoamerican group was from a completely different location.

Norman Sauer (1992) addressed the cultural assessment of race in the work of the forensic anthropologist. In Sauer's (1992) assessment, race had been mostly abandoned as a research tool, and is not a valid representation of human diversity (Sauer 1992). However, when presented with unidentified remains, the forensic anthropologist may be called on to predict, based on skeletal morphology, what cultural label would have been assigned to that person while they were living (Sauer 1992:110). Ancestry is an integral part of the biological profile often required by law enforcement, but determining "race" tends to have a lack of methodological rigor, and no error rates for visual analysis are presented (Hefner 2009:985). This race label prediction is thus not scientific, but according to Sauer (1992:110) it is often correct, and improves the likelihood of the remains being identified.

The skull is most often used to assess ancestry, and until the advent of the FORDISC computer program, was done by visually assessing a number of nonmetric traits (Burns 1999:154). Traits used in racial descriptions include shape of incisors, palatal shape, and the size of the nasal aperture (Burns 1999:154). Hefner (2009:991) indicates that none of the individuals analyzed in his study had all 11 expected trait values expected for the socially attributed race. In earlier works by Hefner (2009:991) smaller numbers of traits were assessed, and only 17% to 51% of individuals presented all traits. Hefner (2009:994) concluded that visual methods of assessing race based on extreme trait expressions are not reliable for estimating ancestry on a consistent basis.

FORDISC, on the other hand, is a program that allows standard measurements to be fed into discriminant function formulae to produce an assessment of race (Ubelaker, Ross, and Graver 2002). A number of anthropologists have tested the reliability of FORDISC's ability to scientifically predict socially attributed race. Williams, Belcher, and Armelagos (2005) tested FORDISC 2.0 with a set of ancient Nubian crania against the Howell's FORDISC data set that contains populations from ancient Egypt, a nearby area. Ten out of the 42 crania could not be classified at all, and only eight were classified as ancient Egyptian, as they were expected. Others ranged from being classified as Easter Islanders, Norse, and not having any major differences from Japanese and other non-African groups (Williams, Belcher, and Armelagos 2005:342). The samples were also tested against the Forensic Data Base, with results ranging from Japanese to Hispanic and Native American. Though there were no Merotic Nubian samples in the comparative data set, and this could be used to make the argument for the discrepancies in the results, FORDISC is supposed to be able to describe continental cranial variation, which it fails to do (Williams, Belcher, and Armelagos 2005:343).

Ubelaker, Ross, and Graver (2002) also tested FORDISC 2.0 using an older skeletal sample. A group of 95 16th – 17th century Spanish crania were tested against the FDB data set. Of the crania, 44% were classified as white, and 35% as black, with others being described as Hispanic, Japanese, American Indian, Chinese, and Vietnamese. Using the Howell's data set, they were sorted into 21 groups. Again, specific population data were not in the Howell's data set.

Tests of FORDISC's capabilities in regards to samples from populations that are in the FDB source data do not fare much better. Even with a fairly complete specimen and the sex known and an adequate reference sample, Elliot and Collard (2009) were only able to assign correct attribution to two out of 200 tests. Part of the reason this seems like such a low result is that the authors report that the creators of FORDISC recently revealed a difference between the manual and likely outcomes (Elliott and Collard 2009). During a training session, the FORDISC creators noted that a posterior probability of less than 0.8 was more often wrong than not, when the manual lists a posterior probability of less than 0.5 as the threshold (Elliott and Collard 2009).

Ancestral attribution from the postcranial skeleton has been tested on a few occasions, the most notable being anterior femoral curvature. T. Dale Stewart's (1962) assessment was that there was no substantial discrimination between "blacks, whites, and South Dakota Indians". More recently, M. E. Ballard (1999) used a different set of measurements, and claims 88.15% and 86.10% accuracy rates for the right and left femur, respectively. Ballard's (1999) sample only included those positively identified as "white" or "black".

Furthermore, genetics are mostly disregarded when it comes to the study of stature. When comparing averages across populations, Steckel (1995:1903) makes the assertion that genetic differences are basically canceled, and health status is more accurately reflected by stature. James M. Tanner (Komlos 1994:1) writes that most between-group variation comes from “the cumulative nutritional, hygienic, disease, and stress experience of each of the groups”. Most groups (not including Asiatic populations) may have the same potential for pre-pubertal growth, so if environmental factors are similar, statures may be similar (Ulijaszek 2001:46).

The above examples show numerous problems with attributing ancestry when attempting to apply scientific analyses. The use of FORDISC brings two problems to light, one overt, and one that most people overlook. The inability of the program to accurately ascribe a racial label to “known” samples shows that human variation is not split along continental borders. The second is in how individuals and groups are labeled. The categories in FORDISC are not consistent. The output for one individual may be “black” while another is “Japanese”. The vastly incongruous population subsets that are used are evidence that these descriptions are based on cultural ideas and not scientifically observable differences.

If ancestry cannot be accurately assessed, there is little utility in separating stature estimation formulae into racial categories. The whole practice of using separate “known” sample groups and working towards precise and accurate formulae is lost if they are incorrectly applied. Therefore, in this work, culturally assessed race was not used as a category in the analysis.

The use of linear regression is the standard method of creating stature estimation formulae (Jantz 1992; Ousley 1995; Trotter and Gleser 1952). This method requires a relatively large data set, with more data allowing for better estimations. When there is a strong correlation of data, a best-fitting line can be created to estimate future samples. The slope is calculated by multiplying the correlation (r) by the standard deviations of mean y values divided by the standard deviations of the mean x values. The y-intercept of the line is found by subtracting the slope times the mean of the x values from the mean of the y values.

Confidence intervals in stature estimation are constructed by first dividing the standard deviation by the square root of the sample size. The dividend is multiplied by a constant based on whether the 90% or 95% confidence interval is the goal. That result is then added to and subtracted from the mean to get the upper and lower limits. Since the confidence intervals are conditional on the data, combining them for population specific regression formulae would not be representative of the data.

4 RESULTS

4.1 Reliability of the Sample

With any skeletal population there is the possibility of manufactured population bias. Any collection must be viewed as merely an arbitrarily formed subset of any given population and not an actual representation of the population (Komar and Grivas 2008). Average stature for a sample of living Americans collected as part of the National Health and Nutrition Examination Survey (NHANES) and reported by Steckel (Carter et. al. 2006) is presented in Table 4.1 along with average stature for a similar time frame as the current data set.

Table 4.1 Mean Stature by Year / Decade of Birth

NHANES (Living Stature) by Year		Skeletal Data by Decade	
Males	Mean Stature in mm	Males	Mean Stature in mm
1940	1767	1940s	1767
1945	1770		
1950	1773	1950s	1752
1955	1776		
1960	1779	1960s	1771
1965	1773		
Females		Females	
1940	1631	1940s	1622
1945	1633		
1950	1631	1950s	1643
1955	1641		
1960	1642	1960s	1631
1965	1633		

The NHANES data are not directly comparable to the current data for a number of reasons. The NHANES data reflect those born in specific years, while the current data have been combined by the decade due to the small sample size. NHANES statures are measured, while the current data are mostly self-reported. Though this is the case, these data are included as a non-statistical assessment of compatibility of the sample.

4.2 Descriptive Statistics

Overall statistics are shown in Table 4.2. Of note is the maximum estimated year of death of 2013. The individual in question was reportedly born in 1956, and died at the age of 57. The individual became part of the collection in 2007, and so the year of death is most likely 2006 or 2007, as suggested by accession dates of other individuals which tend to fall in the year the individual passed away or in the year following. Correcting for either a mistake in reported year of birth or age, the individual still fits into the criteria for data collection.

Table 4.2 Descriptive Statistics for All Individuals

	N	Minimum	Maximum	Mean	Std. Deviation
Year of Birth	229	1940	1983	1953.59	8.915
Estimated Year of Death	229	1977	2013	2003.55	5.31824
Age	229	23.00	66.00	49.9651	9.81132
Stature mm	229	1473.20	1955.80	1723.9432	102.51051
Femur Maximum Length	229	390.00	546.00	461.6594	30.11684
Femur Bicondylar Length	229	386.00	542.00	457.7948	30.23804
Femur Upper Breadth	229	78.11	113.69	96.5154	7.52499
Femur Midshaft Transverse Diameter	229	20.31	47.68	27.1585	2.87803
Fibula Maximum Length	229	318.00	452.00	378.0218	27.18011
Fibula Maximum Midshaft Diameter	229	10.36	22.73	15.9744	2.08262
Femur Maximum Length Plus Fibula Maximum Length	229	712.00	998.00	839.6812	56.36456
Valid N (listwise)	229				

Analysis of variance was run on the sample to verify that males and females represented separate categories. ANOVA was chosen in place of a t-test in order to assess the F-ratio. The results, all of which are significant, are shown in Table 4.3.

Table 4.3 ANOVA for Males and Females

		Sum of Squares	df	Mean Square	F	Sig.
Stature	Between Groups	806735.952	1	806735.952	115.235	.000
	Within Groups	1589180.090	227	7000.793		
	Total	2395916.042	228			
Femur Maximum Length	Between Groups	63535.280	1	63535.280	100.669	.000
	Within Groups	143266.152	227	631.128		
	Total	206801.432	228			
Femur Bicondylar Length	Between Groups	68908.826	1	68908.826	112.083	.000
	Within Groups	139560.528	227	614.804		
	Total	208469.354	228			
Femur Upper Breadth	Between Groups	6158.251	1	6158.251	207.027	.000
	Within Groups	6752.355	227	29.746		
	Total	12910.606	228			
Femur Midshaft Transverse Diame-ter	Between Groups	349.519	1	349.519	51.553	.000
	Within Groups	1539.021	227	6.780		
	Total	1888.540	228			
Fibula Maximum Length	Between Groups	53112.470	1	53112.470	104.544	.000
	Within Groups	115324.421	227	508.037		
	Total	168436.891	228			
Fibula Maximum Midshaft Diameter	Between Groups	124.888	1	124.888	32.811	.000
	Within Groups	864.022	227	3.806		
	Total	988.910	228			
Femur Maximum Length Plus Fibula Maximum Length	Between Groups	232828.913	1	232828.913	107.528	.000
	Within Groups	491518.817	227	2165.281		
	Total	724347.729	228			

The sample was separated by sex, and descriptive statistics are presented for males in Table 4.4 and for females in Table 4.5.

Table 4.4 Descriptive Statistics for Males

	N	Minimum	Maximum	Mean	Std. Deviation
Year of Birth	161	1940	1981	1953.58	8.664
Estimated Year of Death	161	1978	2008	2003.5155	5.31755
Age	161	23.00	66.00	49.9317	9.94932
Stature mm	161	1473.20	1955.80	1762.5168	88.18283
Femur Maximum Length	161	413.00	546.00	472.4845	25.87545
Femur Bicondylar Length	161	410.00	542.00	469.0683	25.50763
Femur Upper Breadth	161	88.19	113.69	99.8856	5.77224
Femur Midshaft Transverse Diameter	161	23.00	47.68	27.9614	2.64805
Fibula Maximum Length	161	333.00	452.00	387.9193	23.34710
Fibula Maximum Midshaft Diameter	161	11.00	22.73	16.4543	1.95659
Femur Maximum Length Plus Fibula Maximum Length	161	749.00	998.00	860.4037	48.00435
Valid N (listwise)	161				

Table 4.5 Descriptive Statistics for Females

	N	Minimum	Maximum	Mean	Std. Deviation
Year of Birth	68	1940	1983	1953.59	9.550
Estimated Year of Death	68	1977	2013	2003.6324	5.35850
Age	68	24.00	66.00	50.0441	9.54867
Stature mm	68	1473.20	1828.80	1632.6147	71.75687
Femur Maximum Length	68	390.00	489.00	436.0294	23.22503
Femur Bicondylar Length	68	386.00	481.00	431.1029	23.00496
Femur Upper Breadth	68	78.11	100.56	88.5360	4.60588
Femur Midshaft Transverse Diameter	68	20.31	32.63	25.2576	2.49499
Fibula Maximum Length	68	318.00	405.00	354.5882	20.48315
Fibula Maximum Midshaft Diameter	68	10.36	20.21	14.8381	1.93747
Femur Maximum Length Plus Fibula Maximum Length	68	712.00	890.00	790.6176	42.81373
Valid N (listwise)	68				

4.3 Secular Change

To determine if there has been significant change between the Terry Collection population and the current research population, the mean statures were compared. Table 4.6 shows average statures and standard deviations for the female groups. Results of ANOVA on the statures of females are contained in Table 4.7. The same analyses were run on males in both groups and are presented in Table 4.8 and 4.9.

Table 4.6 Group Statistics for Females

	Source	N	Mean	Std. Deviation	Std. Error Mean
Stature in mm	Terry Collection	485	1607.6495	67.78857	3.07812
	Current Research	68	1632.6147	71.75687	8.70180
Femur Maximum Length	Terry Collection	485	434.7979	24.61666	1.11778
	Current Research	68	436.0294	23.22503	2.81645
Fibula Maximum Length	Terry Collection	485	352.1567	21.89966	.99441
	Current Research	68	354.5882	20.48315	2.48395
Femur Plus Fibula Maximum Lengths	Terry Collection	485	786.9546	45.20411	2.05261
	Current Research	68	790.6176	42.81373	5.19193

Table 4.7 ANOVA for Terry Collection and Current Research Females

		Sum of Squares	df	Mean Square	F	Sig.
Stature in mm	Between Groups	37170.325	1	37170.325	7.972	.005
	Within Groups	2569106.678	551	4662.626		
	Total	2606277.003	552			
Femur Maximum Length	Between Groups	90.443	1	90.443	.151	.697
	Within Groups	329434.139	551	597.884		
	Total	329524.582	552			
Fibula Maximum Length	Between Groups	352.603	1	352.603	.747	.388
	Within Groups	260234.561	551	472.295		
	Total	260587.165	552			
Femur Plus Fibula Maximum Lengths	Between Groups	800.205	1	800.205	.397	.529
	Within Groups	1111823.061	551	2017.828		
	Total	1112623.266	552			

Table 4.8 Group Statistics for Males

	Source	N	Mean	Std. Deviation	Std. Error Mean
Stature in mm	Terry Collection	1558	1728.5042	74.00720	1.87495
	Current Research	161	1762.5168	88.18283	6.94978
Femur Maximum Length	Terry Collection	1558	470.7709	26.68546	.67607
	Current Research	161	472.4845	25.87545	2.03927
Fibula Maximum Length	Terry Collection	1558	382.8081	23.82442	.60359
	Current Research	161	387.9193	23.34710	1.84001
Femur Plus Fibula Maximum Lengths	Terry Collection	1558	853.5789	49.10160	1.24398
	Current Research	161	860.4037	48.00435	3.78327

Table 4.9 ANOVA for Terry Collection and Current Research Males

		Sum of Squares	df	Mean Square	F	Sig.
Stature in mm	Between Groups	168809.254	1	168809.254	29.661	.000
	Within Groups	9771986.065	1717	5691.314		
	Total	9940795.318	1718			
Femur Maximum Length	Between Groups	428.492	1	428.492	.605	.437
	Within Groups	1215887.408	1717	708.146		
	Total	1216315.900	1718			
Fibula Maximum Length	Between Groups	3812.042	1	3812.042	6.741	.010*
	Within Groups	970971.568	1717	565.505		
	Total	974783.610	1718			
Femur Plus Fibula Maximum Lengths	Between Groups	6796.646	1	6796.646	2.831	.093
	Within Groups	4122582.547	1717	2401.038		
	Total	4129379.194	1718			

*Actual value: 0.0095

4.4 Correlations

Correlations between all measurements taken for males are shown in Table 4.6. Correlations for maximum length of the femur, bicondylar length of the femur, and maximum length of the fibula to stature are all strong. Upper breadth of the femur is moderately correlated to both maximum length of the femur and to stature. Midshaft diameter of the femur is weakly correlated with stature, and diameter of the fibula shows very little correlation.

Correlations for females are found in Table 4.7. Maximum length of the femur, bicondylar length of the femur, and maximum length of the fibula and upper breadth of the femur are only moderately correlated with stature in females. Upper breadth of the femur is still only moderately correlated with the maximum length of the femur in females. Both midshaft diameter measurements show little correlation with stature in females.

4.5 Regressions

All of the long bone lengths and the upper breadth of the femur were moderately to highly correlated measurements, and were regressed onto stature. Additionally, upper breadth of the femur was regressed onto maximum length of the femur. Figures 4.1 through 4.10 show graphs of these measurements and regression lines and are found at the end of chapter 4. The equations for the measurements are found in table 4.8.

Table 4.10 Correlations for Males

		Stature mm	Femur Maximum Length	Femur Bicondylar Length	Femur Upper Breadth	Femur Midshaft Transverse Diameter	Fibula Maximum Length	Fibula Maximum Midshaft Diameter	Femur Maximum Length Plus Fibula Maximum Length
Stature mm	Pearson Correlation	1	.779**	.776**	.526**	.300**	.774**	.127	.796**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.108	.000
	N	161	161	161	161	161	161	161	161
Femur Maximum Length	Pearson Correlation	.779**	1	.998**	.638**	.334**	.902**	.149	.978**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.060	.000
	N	161	161	161	161	161	161	161	161
Femur Bicondylar Length	Pearson Correlation	.776**	.998**	1	.647**	.342**	.905**	.145	.978**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.066	.000
	N	161	161	161	161	161	161	161	161
Femur Upper Breadth	Pearson Correlation	.526**	.638**	.647**	1	.437**	.540**	.137	.607**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.083	.000
	N	161	161	161	161	161	161	161	161
Femur Midshaft Transverse Diameter	Pearson Correlation	.300**	.334**	.342**	.437**	1	.332**	.473**	.342**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	161	161	161	161	161	161	161	161
Fibula Maximum Length	Pearson Correlation	.774**	.902**	.905**	.540**	.332**	1	.159*	.973**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.044	.000
	N	161	161	161	161	161	161	161	161
Fibula Maximum Midshaft Diameter	Pearson Correlation	.127	.149	.145	.137	.473**	.159*	1	.158*
	Sig. (2-tailed)	.108	.060	.066	.083	.000	.044		.046
	N	161	161	161	161	161	161	161	161
Femur Maximum Length Plus Fibula Maximum Length	Pearson Correlation	.796**	.978**	.978**	.607**	.342**	.973**	.158*	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.046	
	N	161	161	161	161	161	161	161	161

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4.11 Correlations for Females

		Stature mm	Femur Maximum Length	Femur Bicondylar Length	Femur Upper Breadth	Femur Midshaft Transverse Diameter	Fibula Maximum Length	Fibula Maximum Midshaft Diameter	Femur Maximum Length Plus Fibula Maximum Length
Stature mm	Pearson Correlation	1	.689**	.625**	.585**	.210	.664**	.053	.691**
	Sig. (2-tailed)		.000	.000	.000	.086	.000	.669	.000
	N	68	68	68	68	68	68	68	68
Femur Maximum Length	Pearson Correlation	.689**	1	.946**	.638**	.279*	.919**	-.042	.982**
	Sig. (2-tailed)	.000		.000	.000	.021	.000	.733	.000
	N	68	68	68	68	68	68	68	68
Femur Bicondylar Length	Pearson Correlation	.625**	.946**	1	.623**	.231	.899**	-.071	.943**
	Sig. (2-tailed)	.000	.000		.000	.058	.000	.564	.000
	N	68	68	68	68	68	68	68	68
Femur Upper Breadth	Pearson Correlation	.585**	.638**	.623**	1	.258*	.538**	.059	.603**
	Sig. (2-tailed)	.000	.000	.000		.033	.000	.634	.000
	N	68	68	68	68	68	68	68	68
Femur Midshaft Transverse Diameter	Pearson Correlation	.210	.279*	.231	.258*	1	.351**	.400**	.319**
	Sig. (2-tailed)	.086	.021	.058	.033		.003	.001	.008
	N	68	68	68	68	68	68	68	68
Fibula Maximum Length	Pearson Correlation	.664**	.919**	.899**	.538**	.351**	1	.037	.977**
	Sig. (2-tailed)	.000	.000	.000	.000	.003		.765	.000
	N	68	68	68	68	68	68	68	68
Fibula Maximum Midshaft Diameter	Pearson Correlation	.053	-.042	-.071	.059	.400**	.037	1	-.005
	Sig. (2-tailed)	.669	.733	.564	.634	.001	.765		.966
	N	68	68	68	68	68	68	68	68
Femur Maximum Length Plus Fibula Maximum Length	Pearson Correlation	.691**	.982**	.943**	.603**	.319**	.977**	-.005	1
	Sig. (2-tailed)	.000	.000	.000	.000	.008	.000	.966	
	N	68	68	68	68	68	68	68	68

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4.12 Regression Equations

	Constant	Slope	Std. Error of Est.	Lower CI	Upper CI
Males (mm)					
Femur Maximum Length to Stature	508.41	2.65	55.48	2.987	-2.321
Femur Bicondylar Length to Stature	504.46	2.68	55.82	3.021	-2.343
Upper Breadth of the Femur to Stature	959.85	8.04	75.23	10.055	-6.017
Upper Breadth of the Femur to Femur Maximum Length	186.82	2.86	19.99	3.397	-2.323
Fibula Maximum Length to Stature	628.45	2.92	56.01	3.295	-2.551
Fibula Plus Femur Maximum Lengths	504.00	1.46	53.51	1.635	-1.291
Females (mm)					
Femur Maximum Length to Stature	703.75	2.13	52.37	2.669	-1.591
Femur Bicondylar Length to Stature	792.71	1.95	56.46	2.536	-1.360
Upper Breadth of the Femur to Stature	826.29	9.11	56.66	12.157	-6.057
Upper Breadth of the Femur to Femur Maximum Length	151.22	3.22	18.02	4.154	-2.280
Fibula Maximum Length to Stature	808.38	2.32	54.09	2.957	-1.691
Fibula Plus Femur Maximum Lengths	716.34	1.16	52.23	1.451	-0.867

Table 4.13 ANCOVA Results for Females

	Source	*y*-intercept	SE *y*-int.	Slope	SE Slope	*df*	*t*	Upper CI *y*-int.	Lower CI *y*-int.	Upper CI Slope	Lower CI Slope
Femur Maximum Length	Terry Collection	600.731	29.526	2.316	0.068	484	1.96	658.601	-542.860	2.449	0.133
	Current Research	703.754	120.274	2.130	0.275	67	1.96	939.491	-468.017	2.669	-1.591
Fibula Maximum Length	Terry Collection	735.923	29.837	2.475	0.085	484	1.96	794.404	-677.442	2.642	-2.308
	Current Research	808.375	114.583	2.324	0.323	67	1.96	1032.958	-583.792	2.957	-1.691

Table 4.14 ANCOVA Results for Males

	Source	*y*-intercept	SE *y*-int.	Slope	SE Slope	*df*	*t*	Upper CI *y*-int.	Lower CI *y*-int.	Upper CI Slope	Lower CI Slope
Femur Maximum Length	Terry Collection	602.078	16.761	2.393	0.036	1557	1.96	634.930	-569.226	2.464	-2.322
	Current Research	508.411	80.214	2.654	0.170	160	1.96	665.630	-351.192	2.987	-2.321
Fibula Maximum Length	Terry Collection	743.334	16.934	2.572	0.044	1557	1.96	777.025	-710.643	2.658	-2.486
	Current Research	628.454	73.705	2.923	0.190	160	1.96	772.916	-483.992	3.295	-2.551

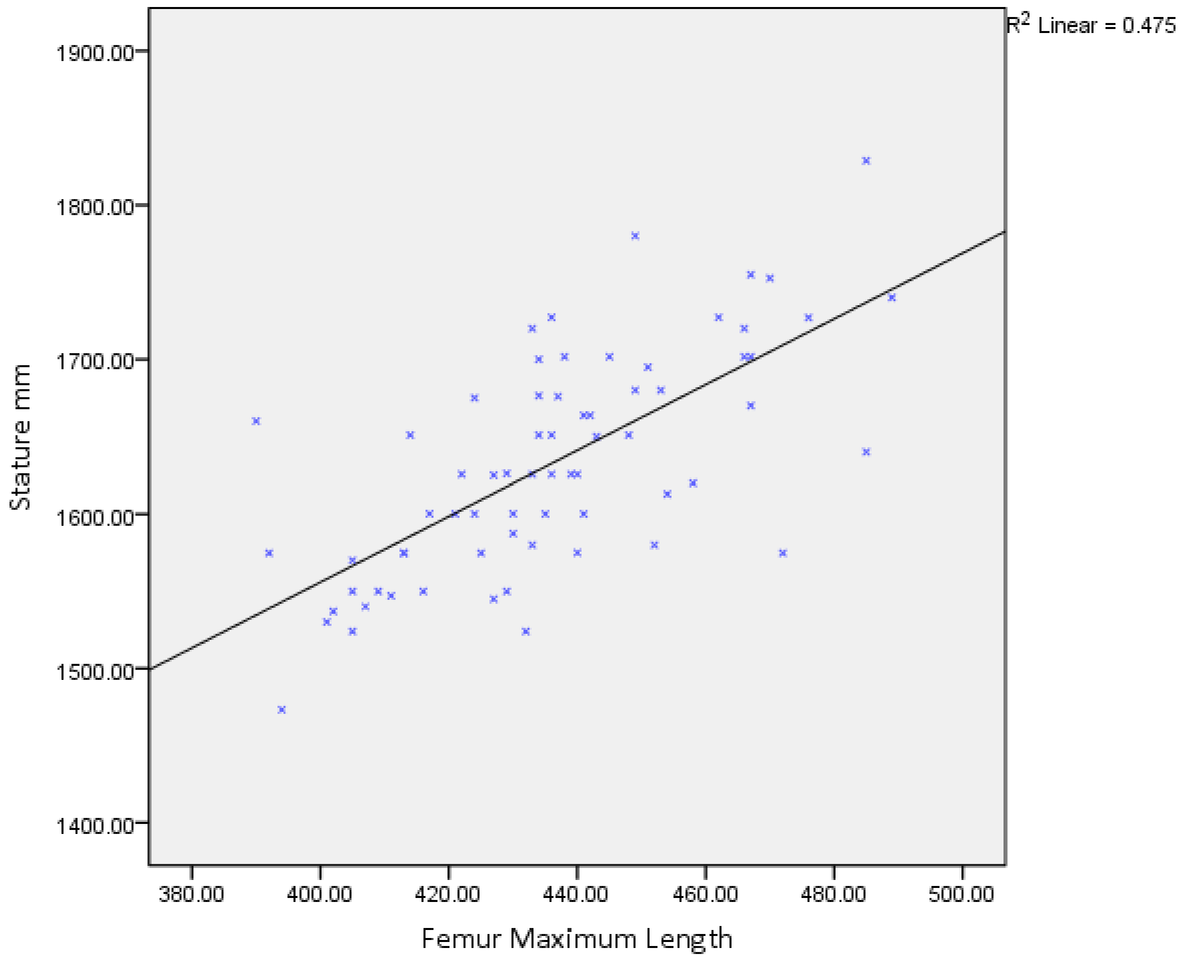

Figure 4.1 Regression of Femur Maximum Length to Stature in Females

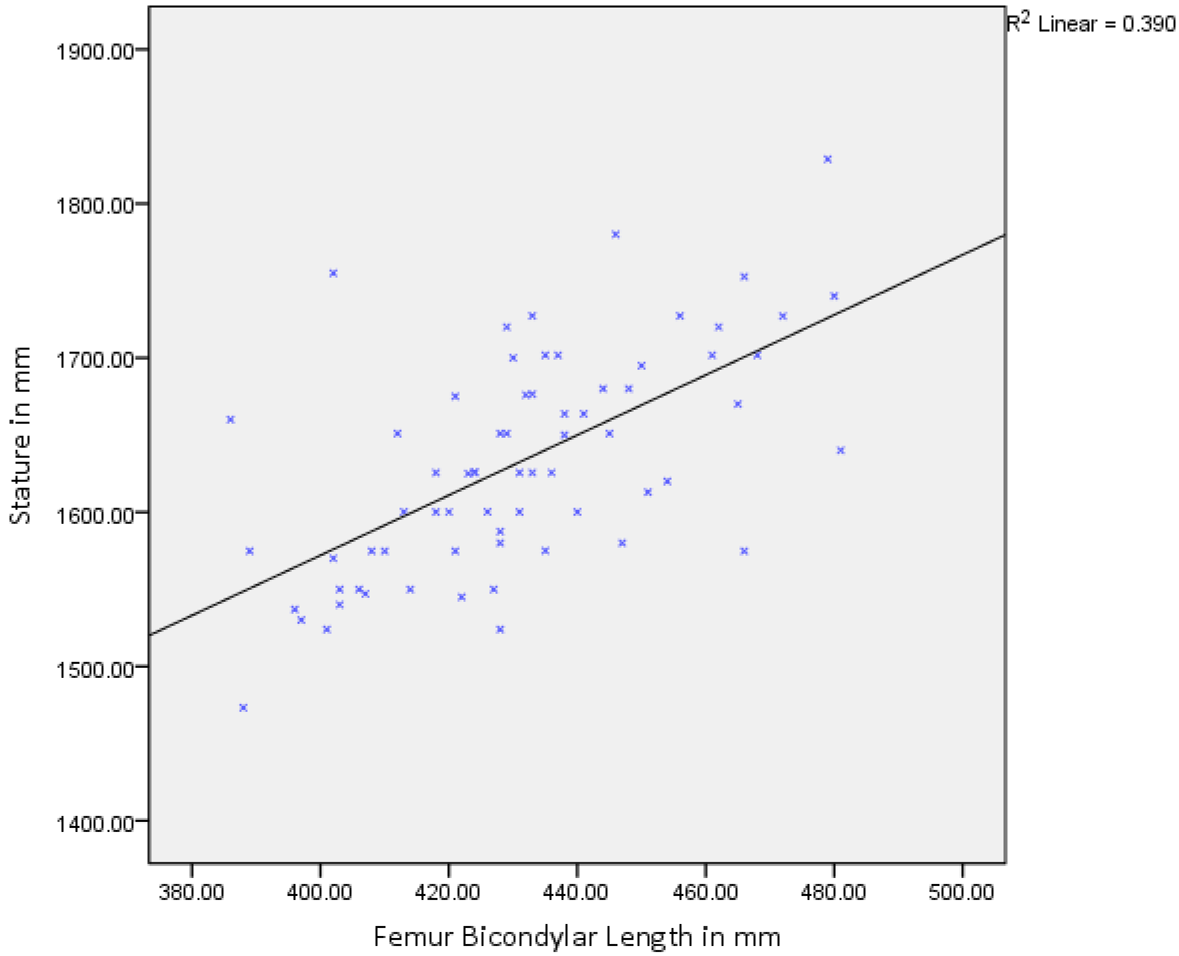

Figure 4.2 Regression of Femur Bicondylar Length to Stature in Females

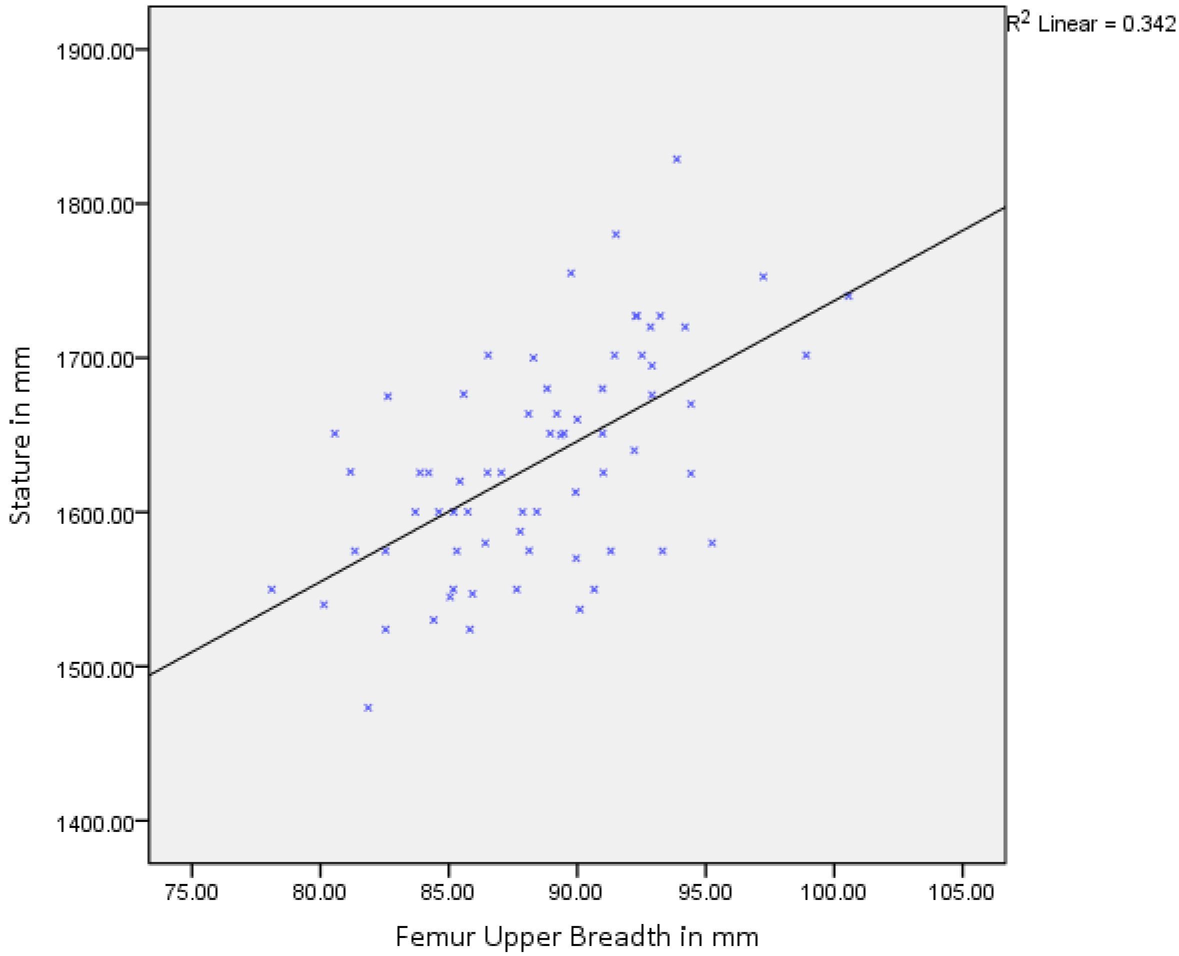

Figure 4.3 Regression of Upper Breadth of the Femur to Stature in Females

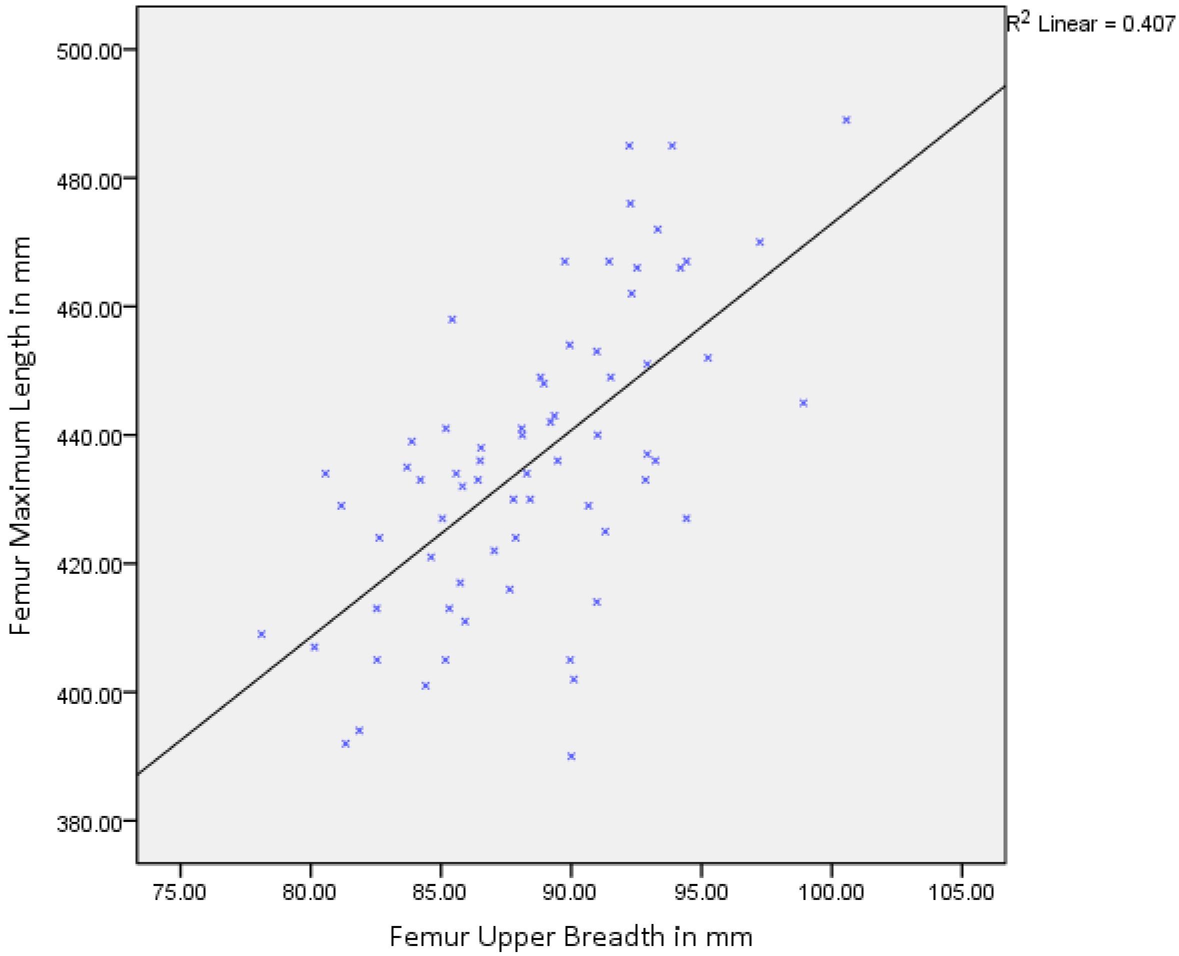

Figure 4.4 Regression of Upper Breadth of the Femur to Femur Maximum Length in Females

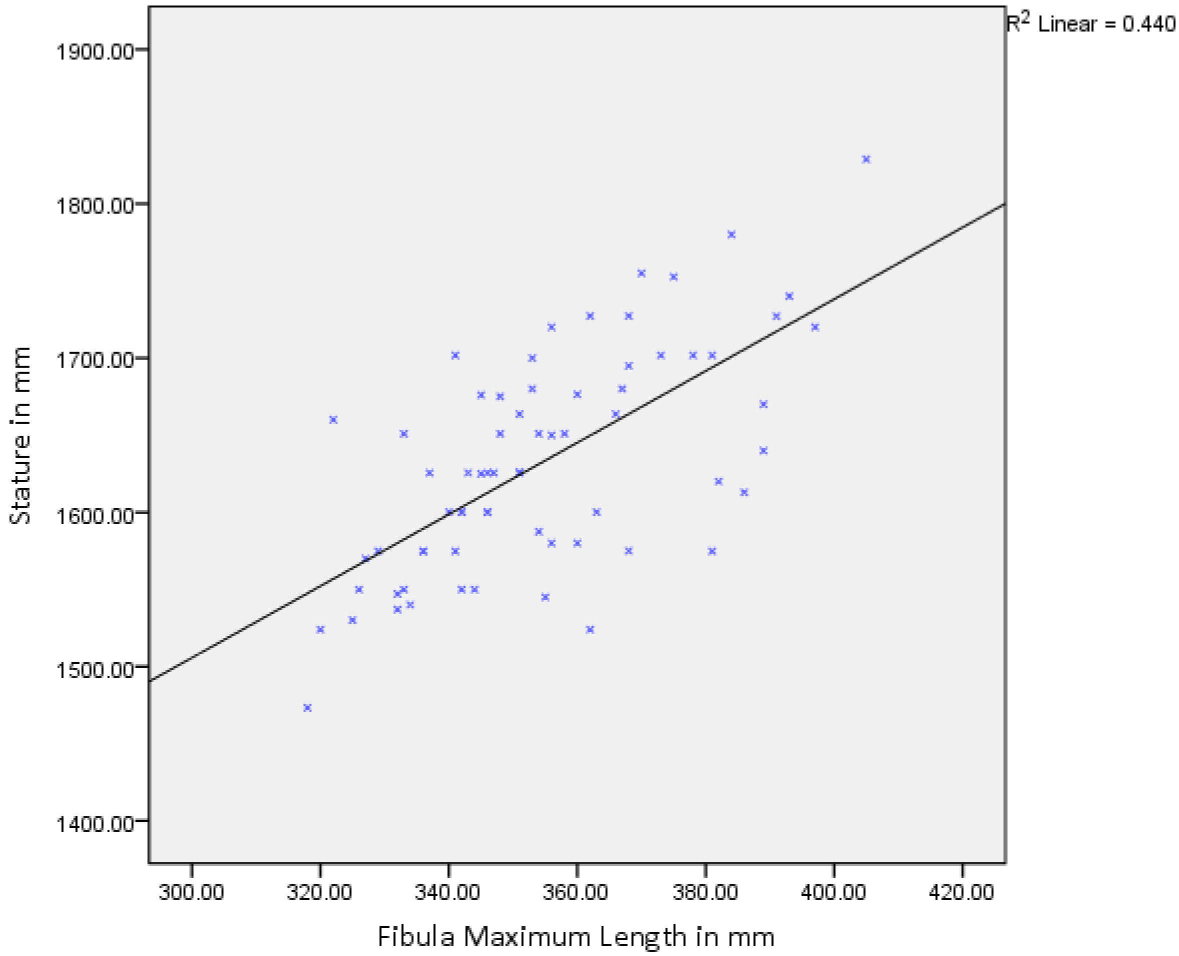

Figure 4.5 Regression of Fibula Maximum Length to Stature in Females

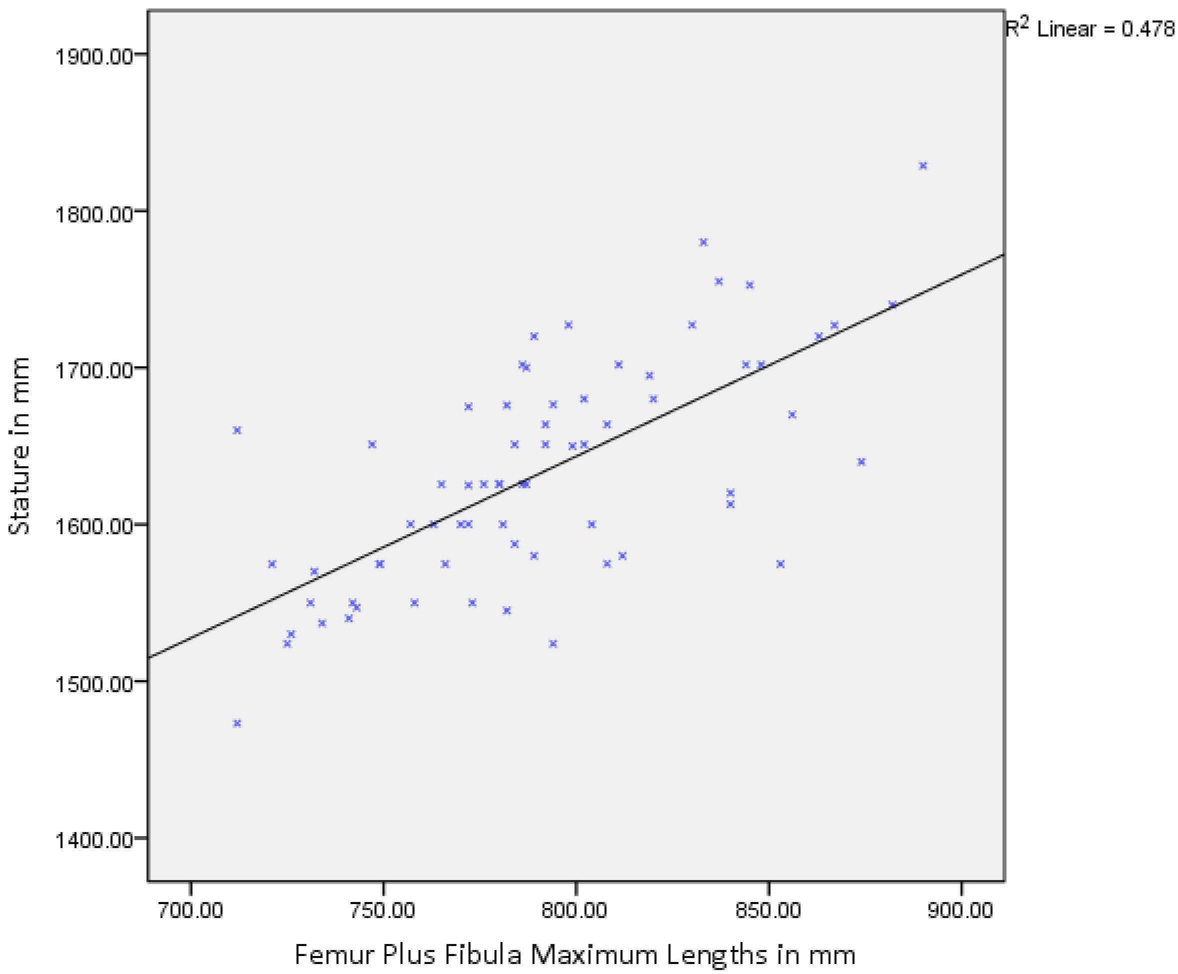

Figure 4.6 Regression of Femur Plus Fibula Maximum Lengths to Stature in Females

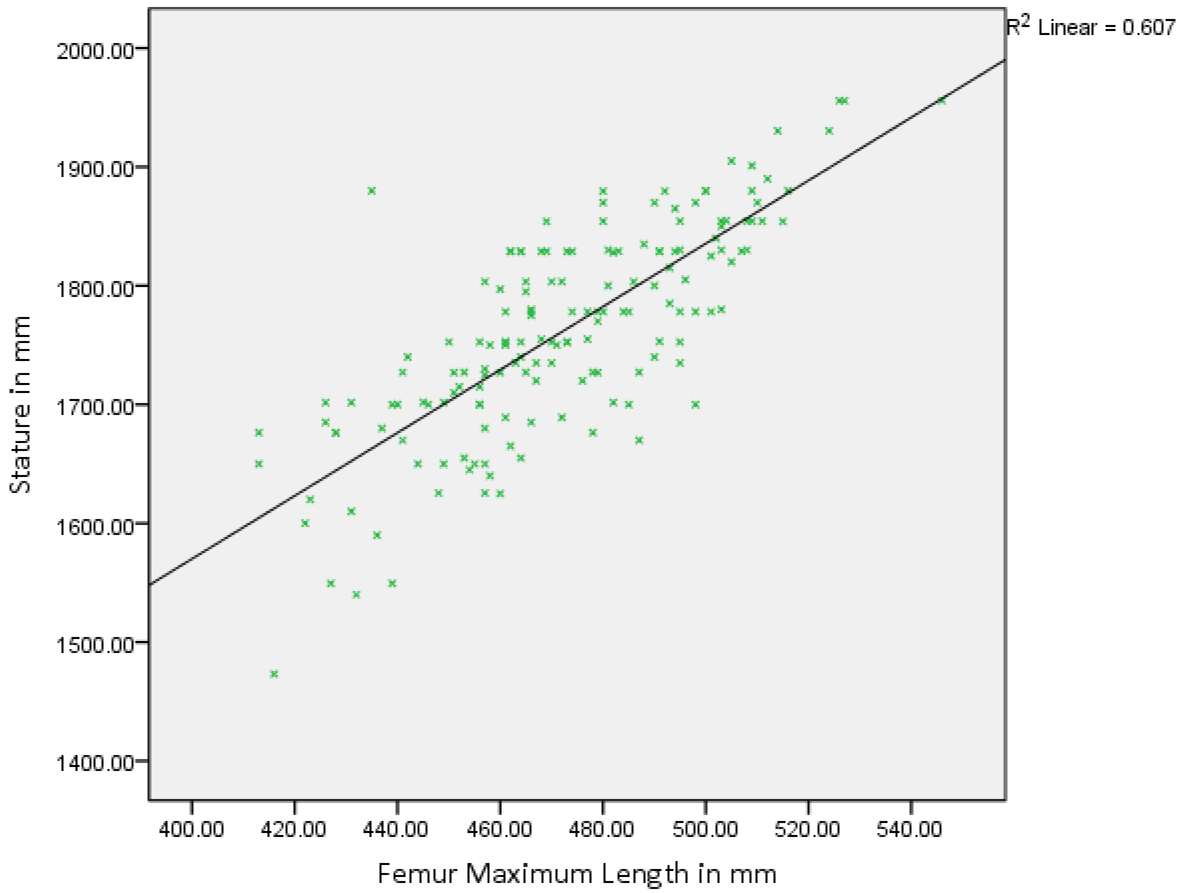

Figure 4.7 Regression of Femur Maximum Length to Stature in Males

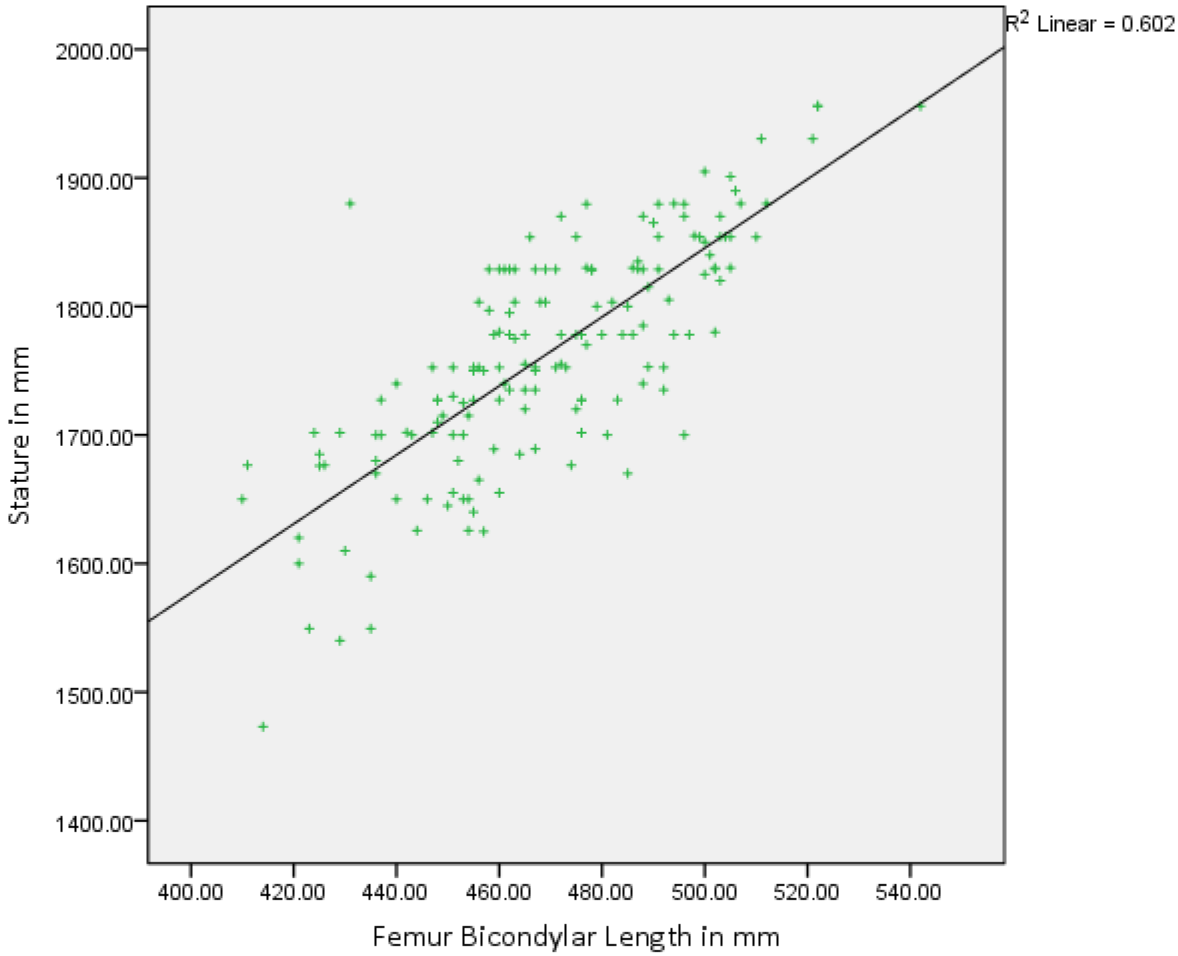

Figure 4.8 Regression of Femur Bicondylar Length to Stature in Males

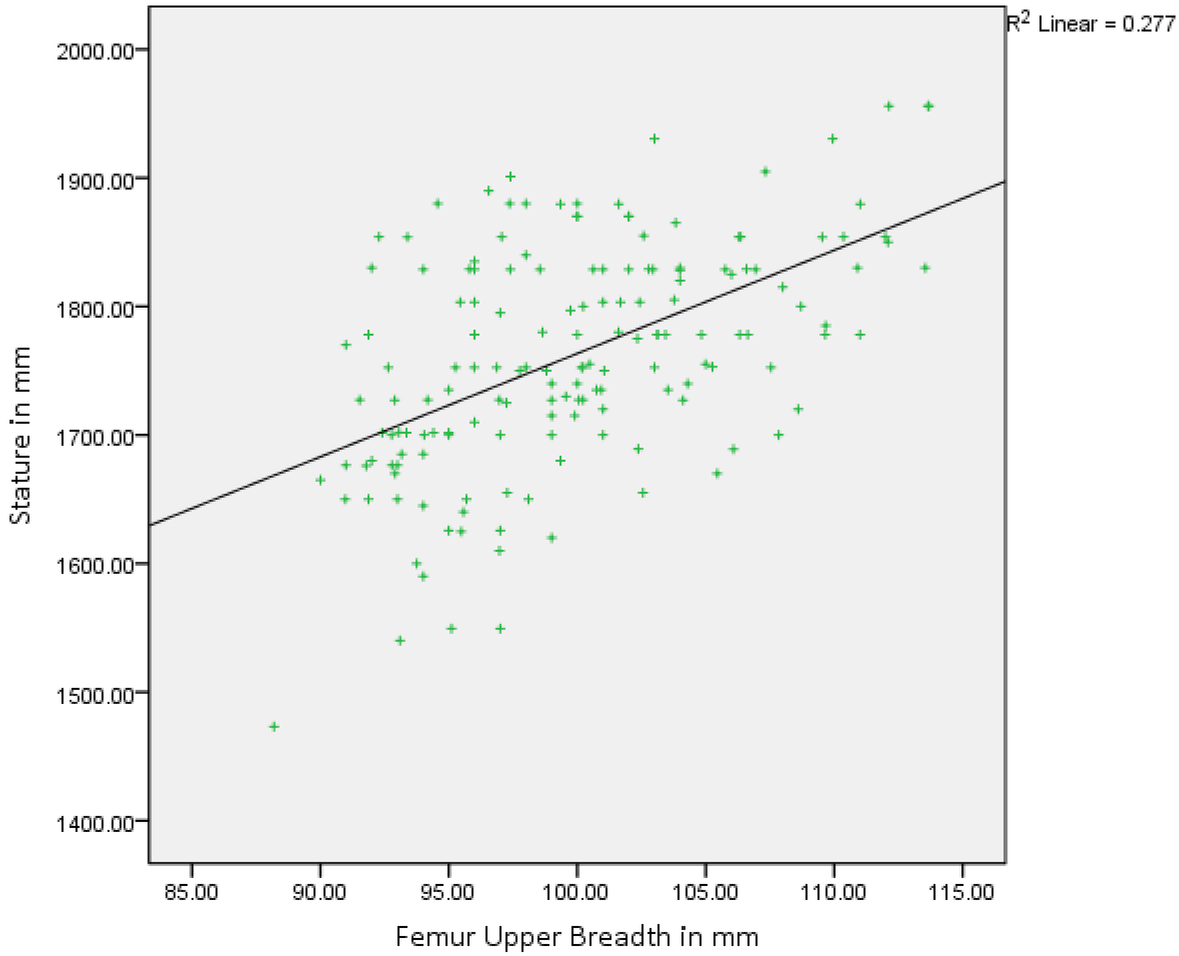

Figure 4.9 Regression of Upper Breadth of the Femur to Stature in Males

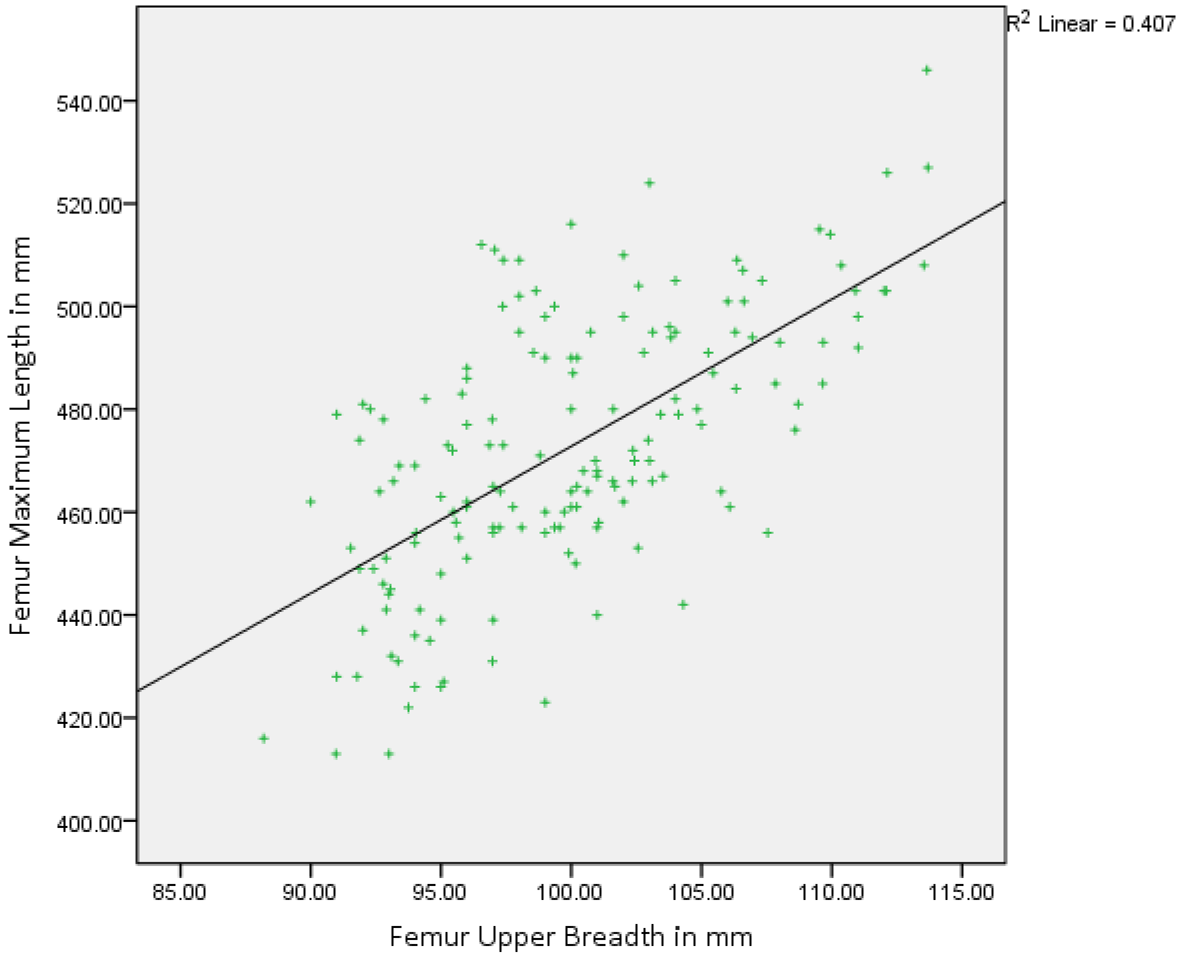

Figure 4.10 Regression of Upper Breadth of the Femur to Femur Maximum Length in Males

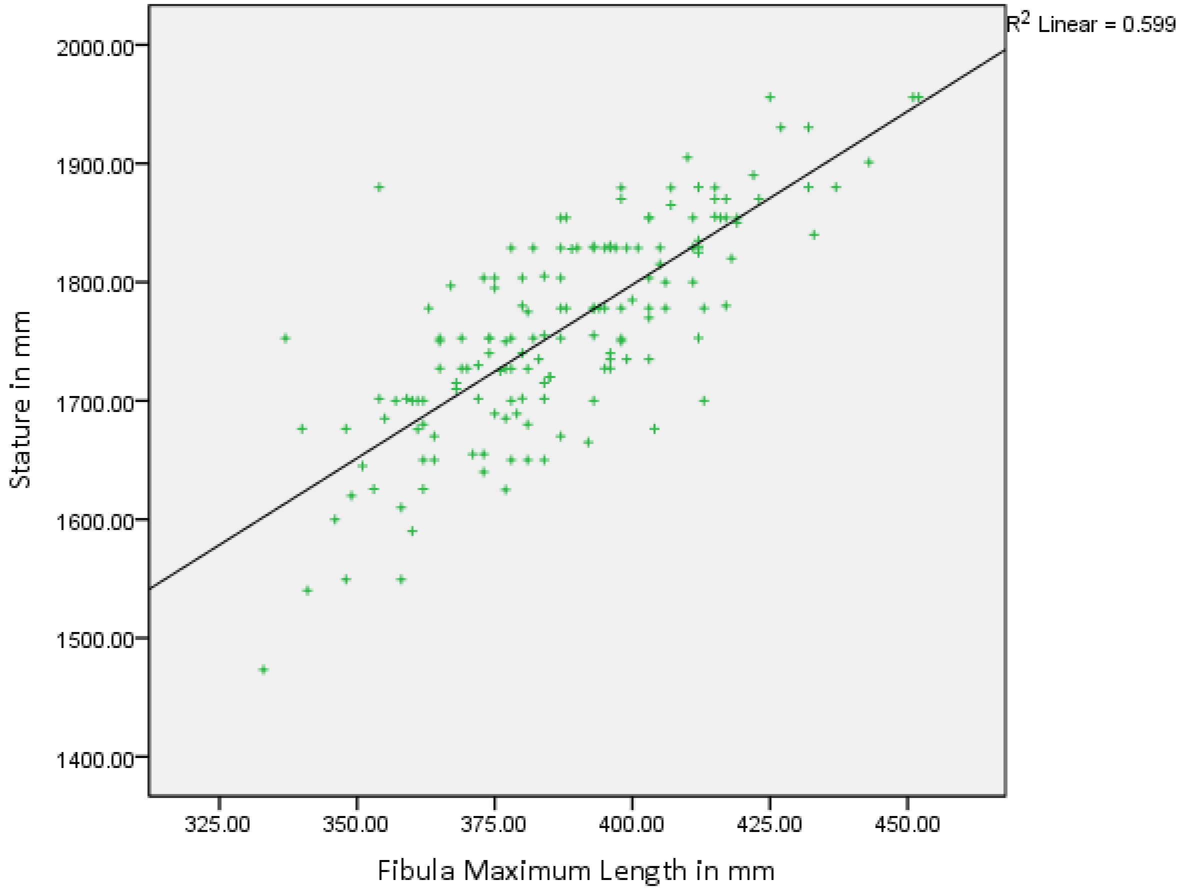

Figure 4.11 Regression of Fibula Maximum Length to Stature in Males

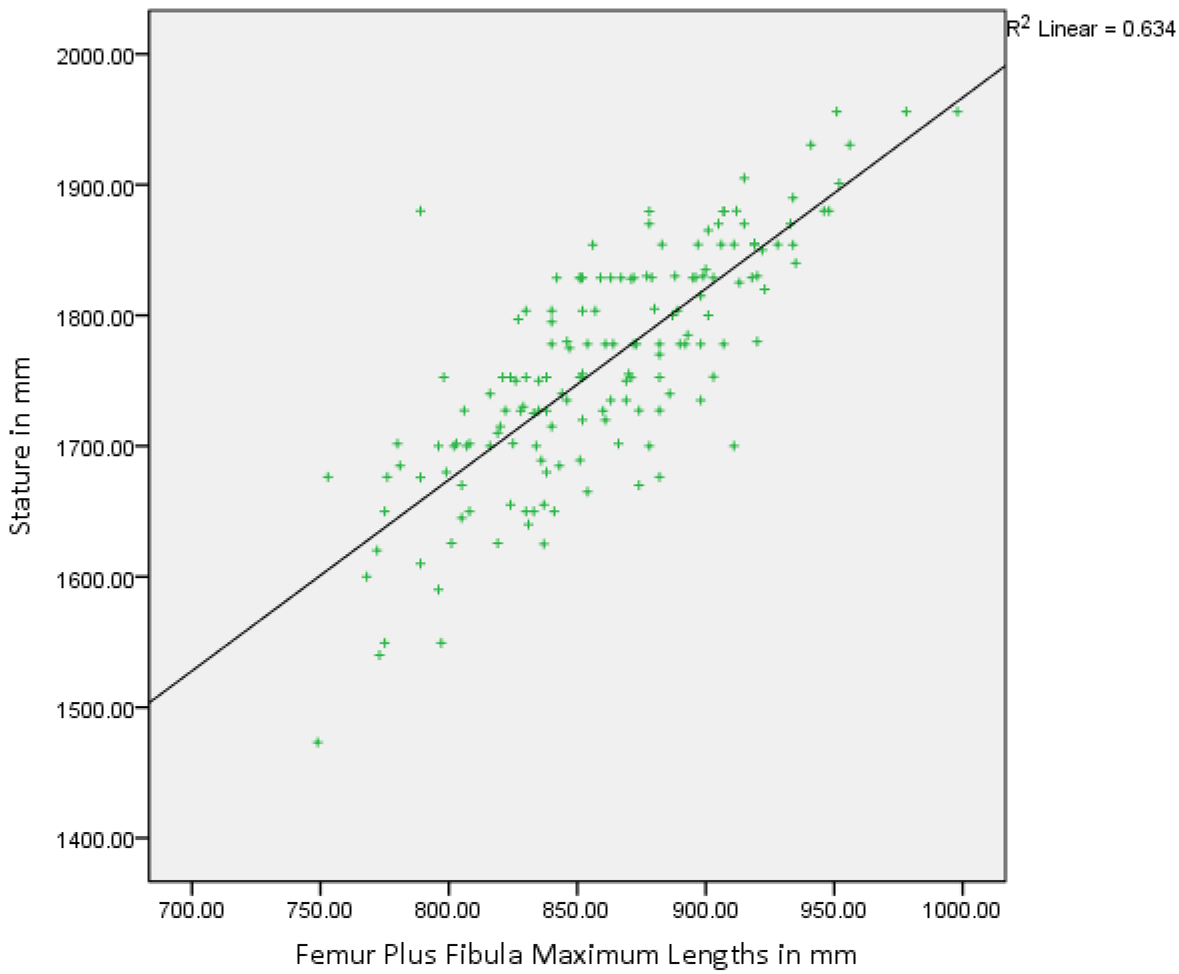

Figure 4.12 Regression of Femur Plus Fibula Maximum Lengths to Stature in Males

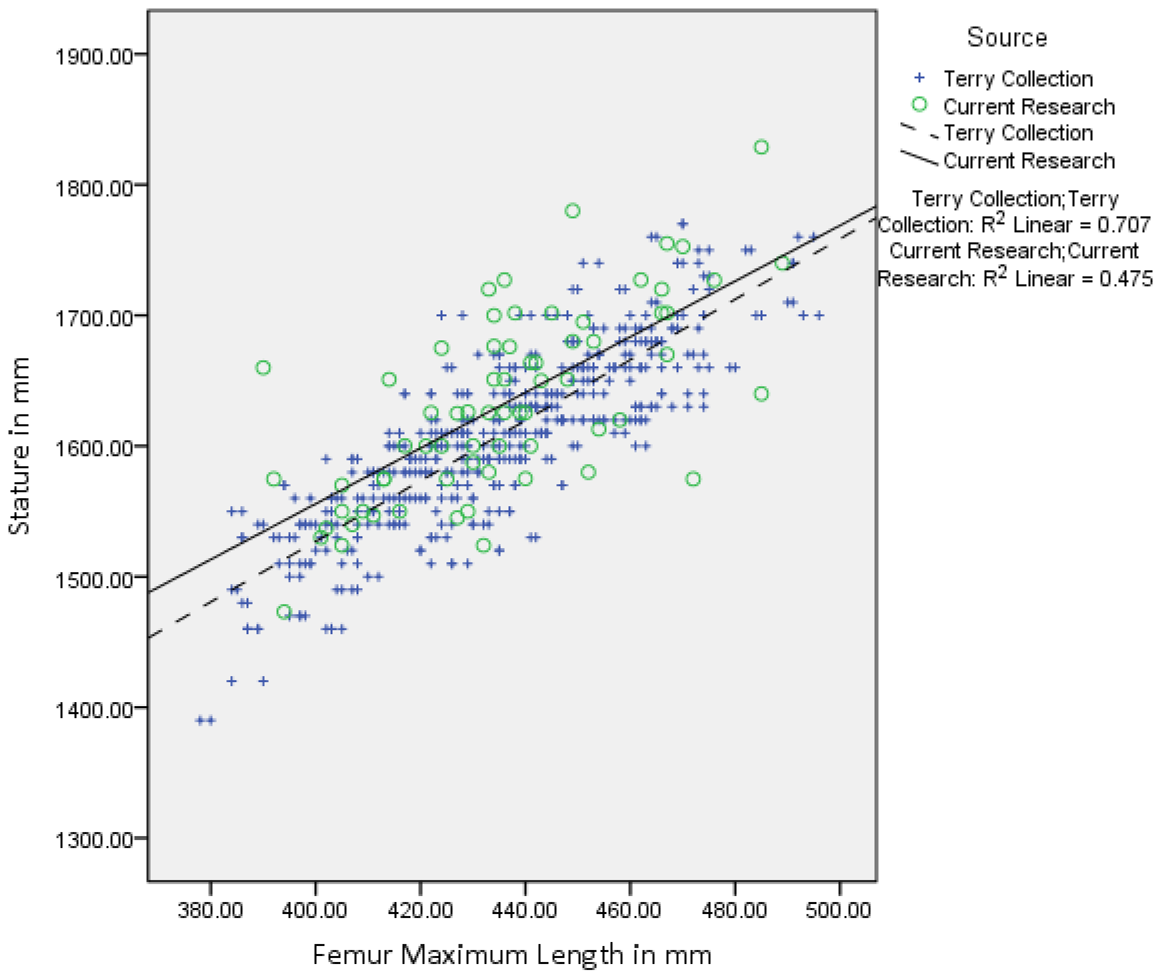

Figure 4.13 Femur to Stature Regressions in Terry and Modern Samples for Females

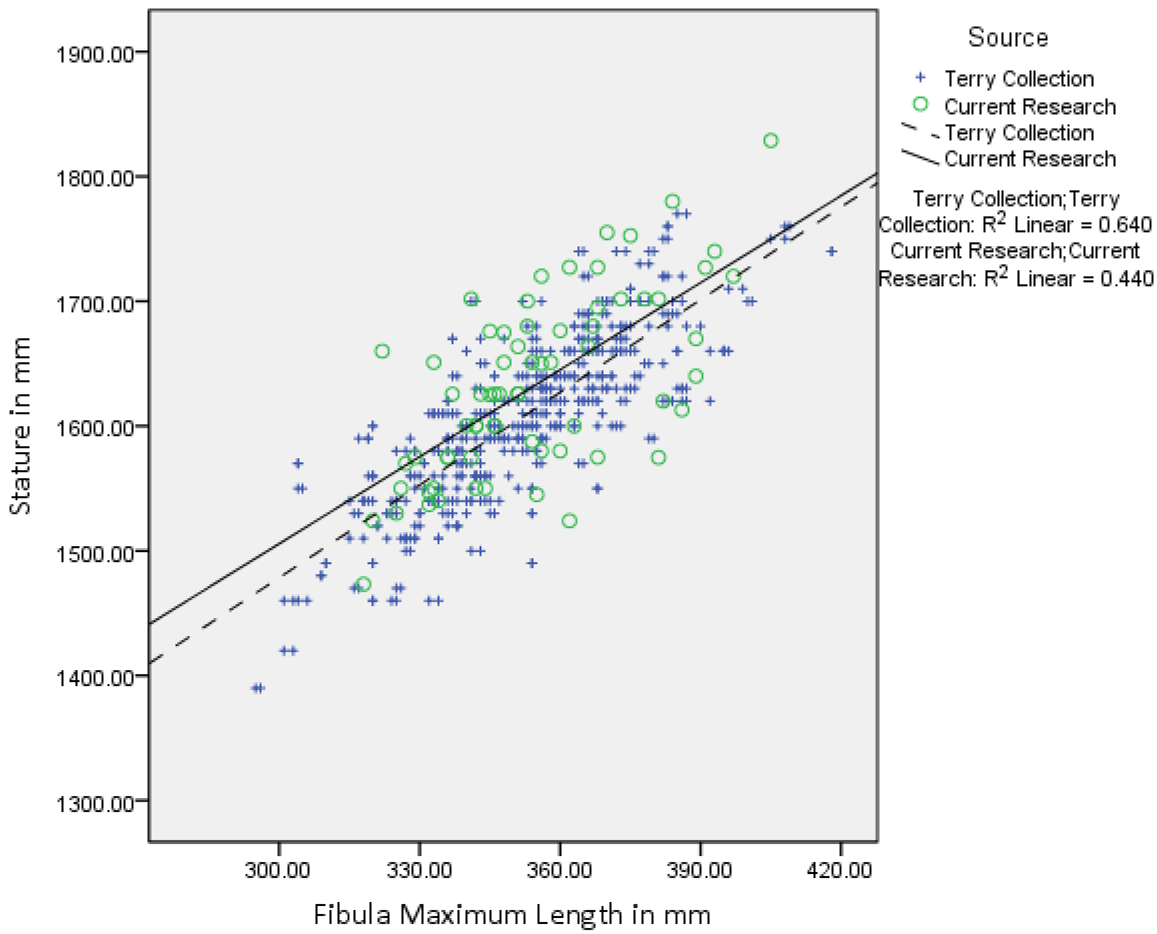

Figure 4.14 Fibula to Stature Regressions in Terry and Modern Samples for Females

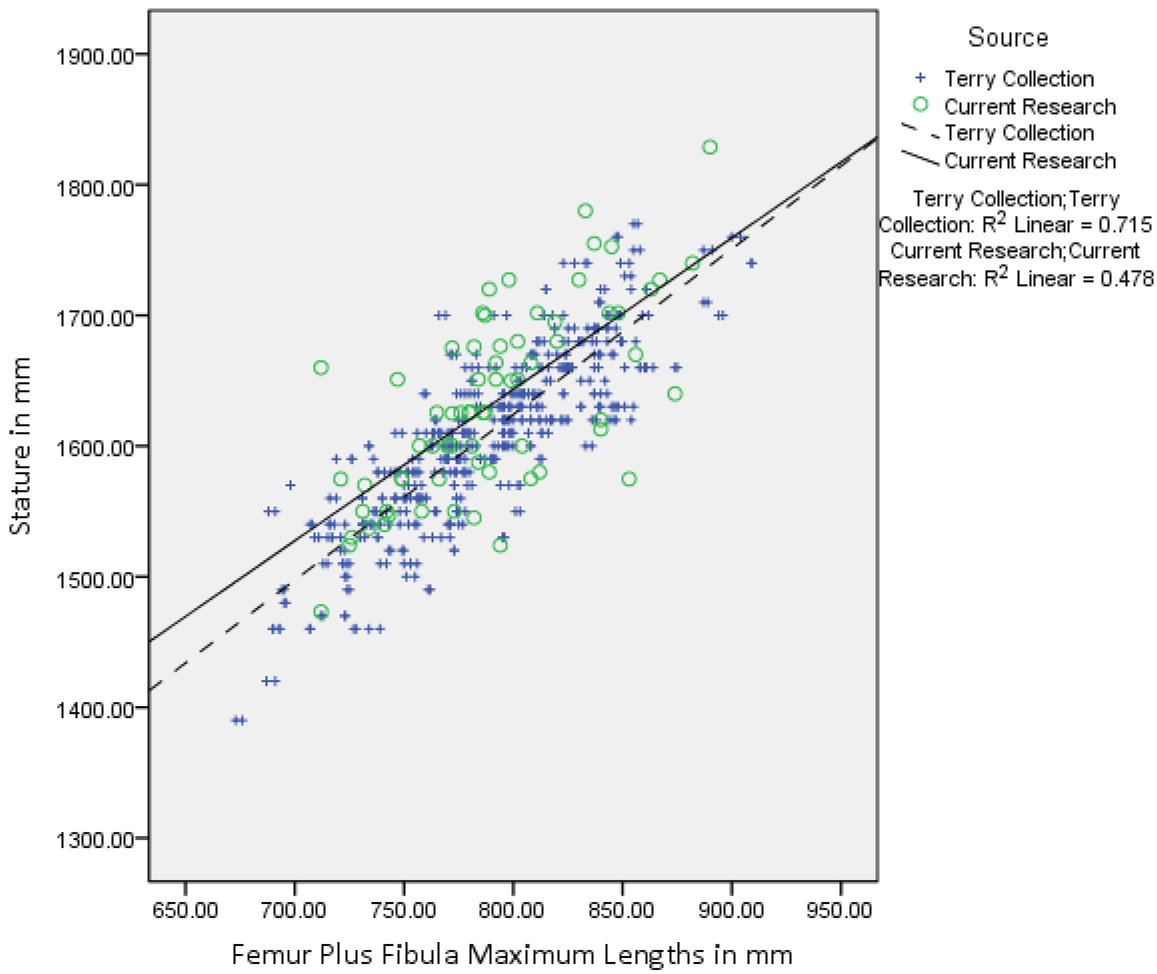

Figure 4.15 Femur Plus Fibula Maximum Lengths Regressions to Stature in Females

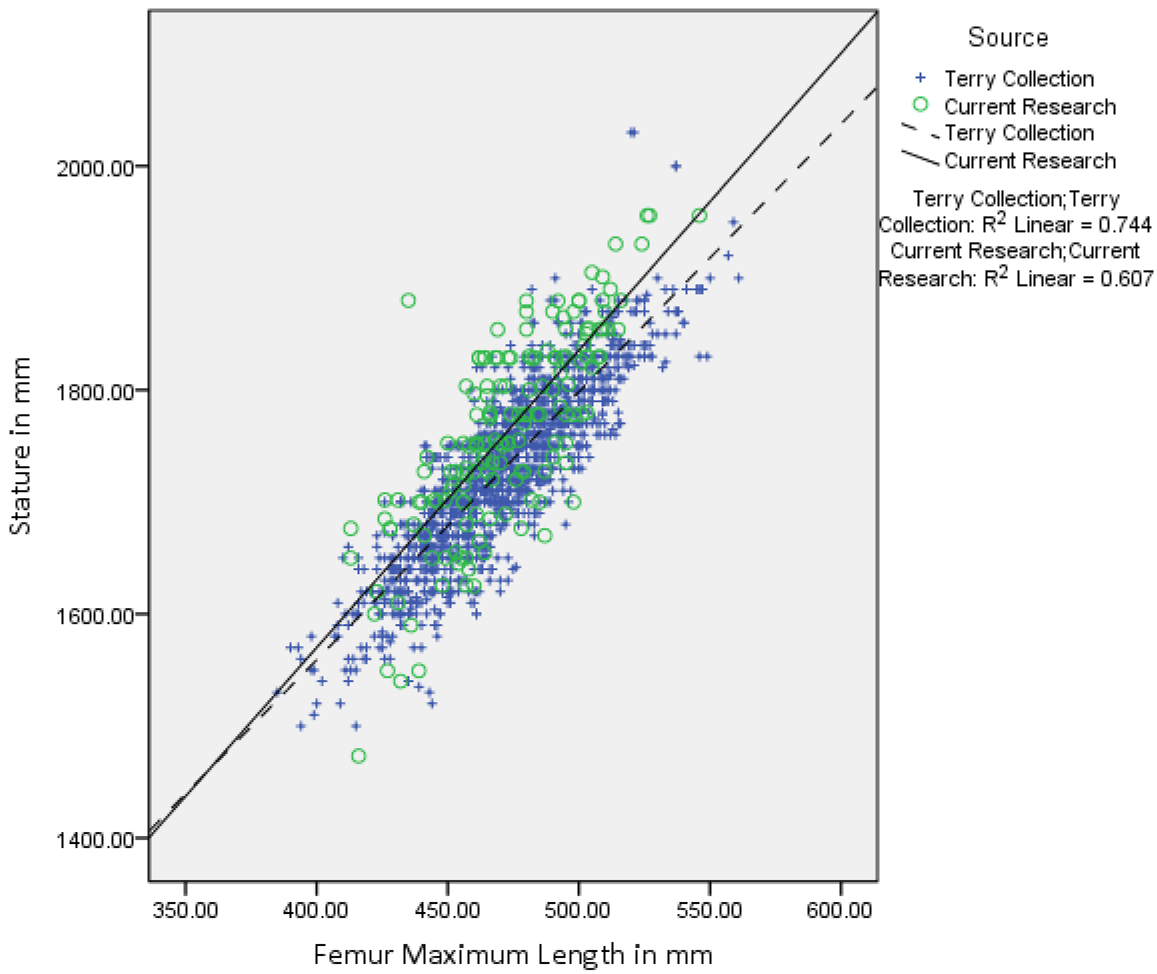

Figure 4.16 Femur to Stature Regressions in Terry and Modern Samples for Males

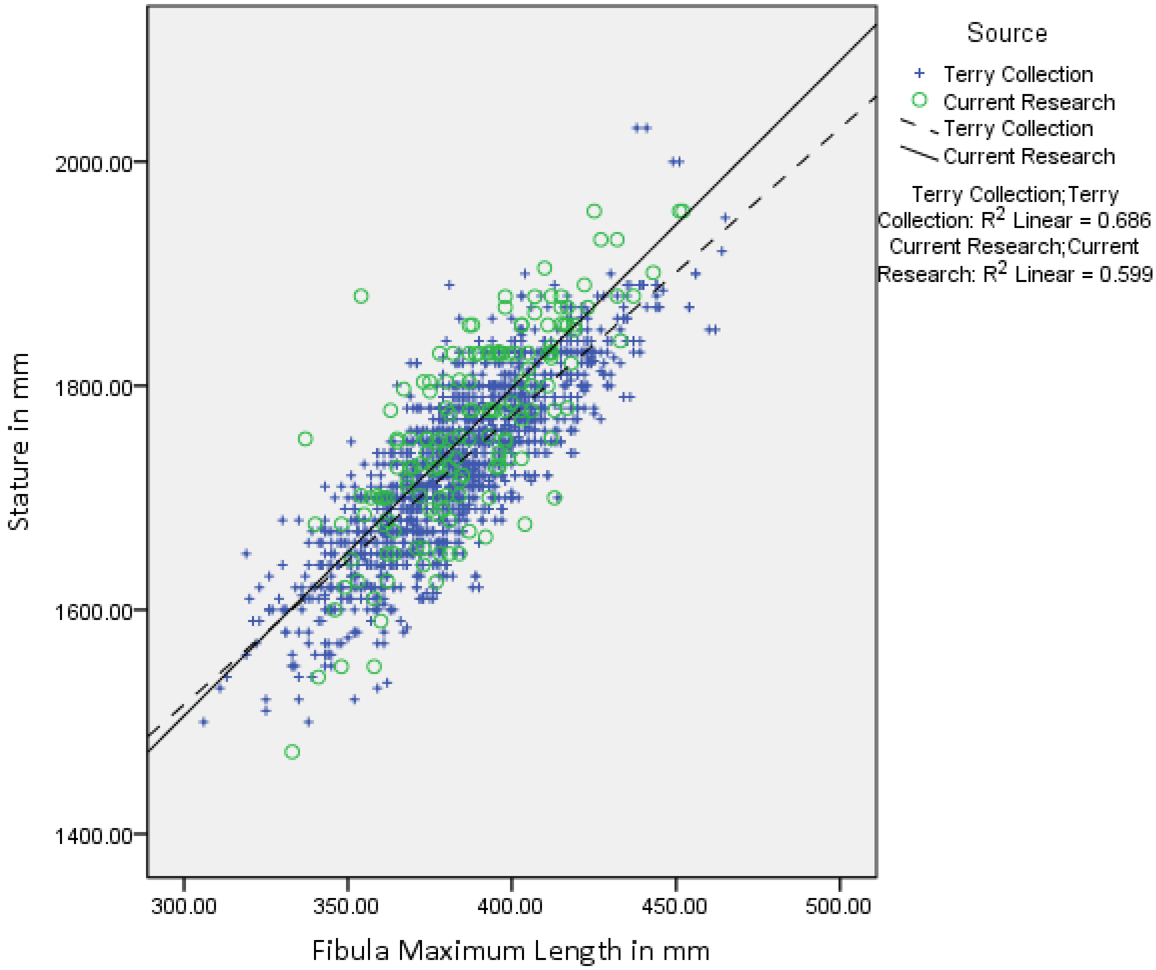

Figure 4.17 Fibula to Stature Regressions in Terry and Modern Samples for Males

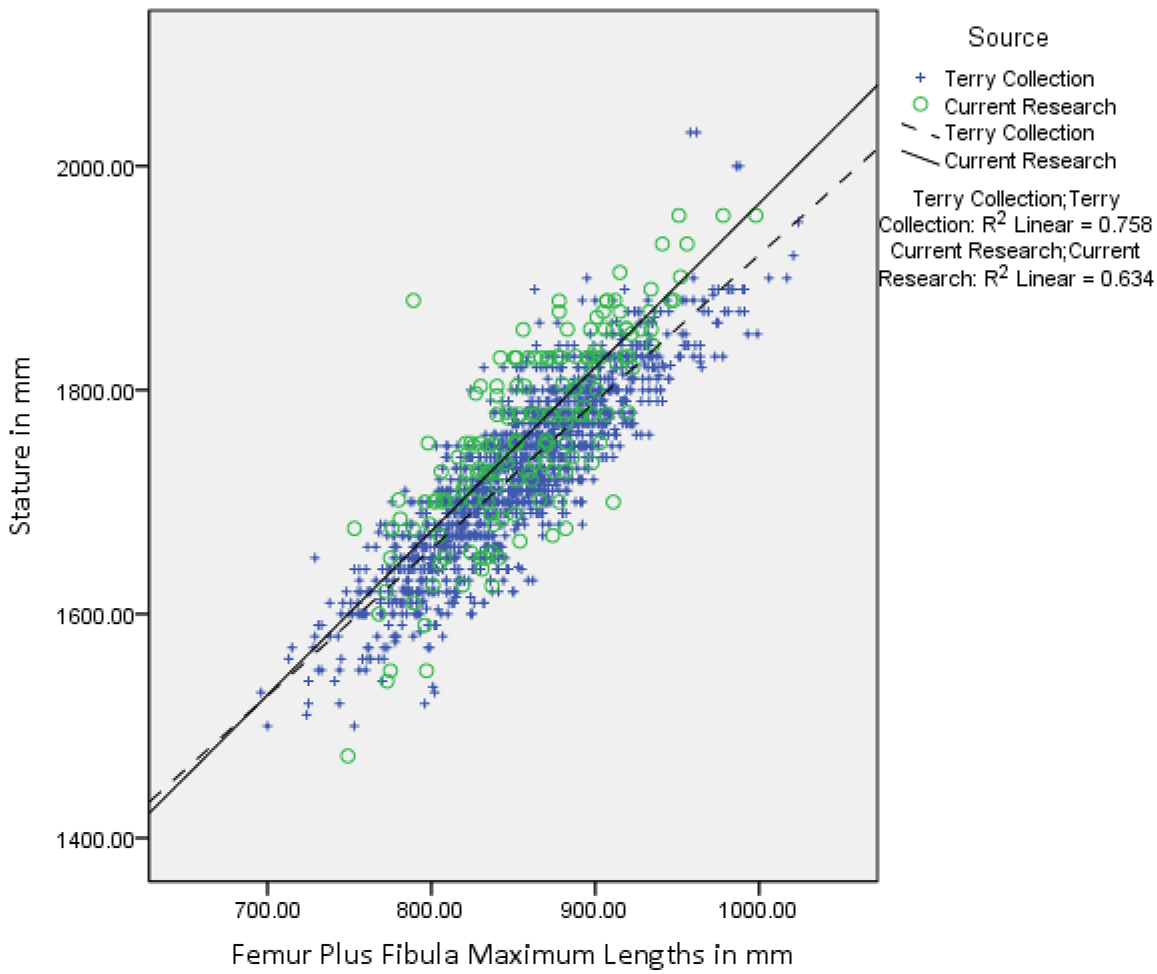

Figure 4.18 Femur Plus Fibula Maximum Lengths Regressions to Stature in Males

5 DISCUSSION

5.1 Reliability of the Sample

When creating stature estimation formulae, the primary concern is that the research population accurately portrays the population on which the formulae will be used. The data in Table 4.1 from the current research were selected to demonstrate average stature within a decade. Only samples from the 1940s, 1950s, and 1960s from the current research were chosen to compare with a similar range provided in the NHANES data.

The data presented in Table 4.1 serve two purposes. The fact that average stature differs no more than 24 mm between any selection of dates for the NHANES and current research groups illustrates that there is little difference between those groups. The second purpose is to show that there are no major secular trends within either population throughout the time period being studied. The samples do show slight variation year to year, but only change a maximum of 21 mm in any group throughout the entire timeframe.

5.2 Sex Differences

Separating the sample by sex is the next issue addressed. Though it could be assumed that males and females are two distinct categories, it is possible that there are some skeletal measurements which have significant overlap between the groups, resulting in the need for only one set of regression equations for those skeletal elements. In order to test the null hypothesis that states males and females form a single group, an analysis of variance (ANOVA) was conducted on stature and each of the measurements taken. As shown in table 4.3, all of the results are significant (< 0.000), with high F-values, indicating that males and females should be treated as separate entities throughout the rest of the analysis.

Descriptive statistics for males and females are laid out in Tables 4.4 and 4.5, respectively. The sample sizes vary greatly, with the number of males well over twice the size of the female sample. The disparity in the sample sizes is due to the distribution of individuals who have donated their remains to be studied anthropologically, with a greater number of males having done so.

Between groups the range of birth years is similar, starting in 1940, the baseline year for data selection. The latest year of birth for females is 1983 and for males it is 1981. The average year of birth for both samples is 1953. Estimated year of death was utilized as not all specimens had dates of death in the information provided by the institutions where data collection took place. Depending on the time of year in which the individuals were born or passed away, these numbers may differ by a year. Estimated year of death for female samples begins in 1977, one year before those of males. The latest estimated year of death is 2008 and not 2013 (as it is impossible), which is the same value as it is with the males. One way to reassess the obviously incorrect estimated year of death is to assume that the date of acquisition fits the pattern of occurring during the same year or just after the year of the individual's death. Reanalyzing the descriptive statistics with the out of place individual's year of death modified to 2006 or 2007 still yields an estimated average year of death of 2003. Males have an average estimated year of death of 2003 as well.

5.3 Secular Increase

There may be marked increase in stature between the Terry Collection and modern samples.This is the impetus for a major portion of the current study. If there has been significant change, it is important to create new stature estimation formulae to be used in modern forensics cases in order to provide law enforcement with accurate descriptions of individuals to match with missing persons reports. Males and females from the Terry Collection and those in the sample collected for the current research were evaluated for differences in order to determine if they were in fact one population.

Raw differences between the Terry Collection and the current research sample females are covered in Table 3.6. Mean stature has increased in approximately 25 mm from the older Terry Collection to the more recent research sample. Increase in mean maximum length of the femur is less than 2 mm, and mean maximum length of the fibula is less than 2.5 mm. These data suggest that there has been a stature increase, though it does not seem to be occurring by an increase in the length of the lower limbs.

ANOVA was performed on the female samples to test the assumptions described above, and the results can be found in Table 4.7. Indeed, stature has increased significantly (< 0.01) from the Terry Collection to the more modern sample drawn from the University of New Mexico and the University of Tennessee. Results from the ANOVA include the fact that the increase in mean length of both the maximum length of the femur with a significance value of 0.697, and that of the fibula at 0.388 do not show statistically substantial change. Combined lengths of femur and fibula also show no significant (0.529) increase either.

Males too increased in stature between the time periods expressed in the samples. Average stature increased by about 34 mm from the Terry Collection to the current research sample. Little of the increase in stature may be attributed to an increase in the average maximum length of the femur, which went up by less than 2 mm. Average length of the fibula on the other hand rose by just over 5 mm.

Subjecting the males of the Terry Collection and current research sample to ANOVA reveals, as with the females, that there has been a significant (< 0.000) increase in stature. Results for maximum length of the femur continue the trend seen in the female data, with the increase not showing up as being significant (0.437). Rise in the length of the fibula in males differs from that in females in that it is significant at the 0.01 level, with an actual value of 0.0095. Combining the fibula and the femur lengths together describe a change that again, as with the females, is not significant (0.093).

5.4 Correlations

Standard length measurements for long bones tend to be the most highly correlated with stature. Table 4.10 clearly shows that with the current male research data this is still the case. Maximum length of the femur is strongly correlated with stature at 0.779, the highest of all the single bone measurements, followed closely by bicondylar length of the femur at 0.776. The length of the fibula is also strongly correlated at 0.774. Combining the maximum length of the femur to the maximum length of the fibula gives an even more strongly correlated result at 0.796. All of the results are significant at the 0.01 level. Diameter measurements for the femur and for the fibula had poor to no correlation at 0.300 and .127 respectively, and are thus no longer used in the analysis.

The experimental measurement, upper breadth of the femur is moderately correlated with stature at 0.526, to maximum length of the femur at 0.638, and slightly higher to bicondylar length of the femur at 0.647. All of these correlations are significant at the 0.01 level. Correlations were similar to those for the unmodified upper femoral measurement tested by Simmons et al. (1990:633). Correlation to stature in males for the upper breadth of the femur in the current study was lower than the 0.587 and 0.564 Simmons et al. (1990:633) have reported for their categories of white and black males, respectively. These moderate correlations mean that while the measurement would not be the best to use if an intact femur were present, there is a relationship between the upper breadth of the femur and stature that can be accessed when only the upper portion of the femur is available.

Correlations for females in the current research sample, displayed in Table 4.11, are similar to those in males in that single length measurements of bones are most highly correlated with stature. The pattern of which measurements are most highly correlated differs between the male and female samples, however. All of the single long bone length measurements are less correlated than those found in males as well. Maximum femur length is again the most highly correlated measurement at 0.689, followed in this sample by the maximum length of the fibula at 0.644, with the least correlated measurement being that of the bicondylar length of the femur with a value of 0.625. Only slightly higher than maximum length of the femur is the combination of the femur and the fibula at 0.691. Even though they are not as highly correlated as the measurements for the males, they are all still significant at the 0.01 level. Femur diameter, at 0.210, and fibula diameter, at 0.053 show no real correlation, and are dropped from any further analyses in the female sample.

Upper breadth of the femur is slightly more highly correlated with stature in females than in males at 0.585. Correlation between the upper breadth of the femur and maximum length of the femur is the same as it is in males at 0.638. With a value of 0.623, the correlation of upper breadth of the femur to bicondylar length of the femur is lower than that found in males. All correlations with the upper breadth of the femur mentioned above are significant at the 0.01 level. Correlation to stature in females is higher in the current study at 0.585 compared to 0.526 and 0.432 for whites and for blacks (Simmons et al. 1990:633). Like the results in the male data, the results in the female data show the possibility of using the upper breadth of the femur to estimate stature.

5.5 Regressions

Regression analyses for those measurements which were moderately to highly correlated with stature were completed for males and females. Additionally, the upper breadth of the femur was regressed onto maximum length of the femur. Regression equations and confidence intervals are presented in Table 4.8. For each equation there is a graph which includes the regression line.

As a final test to determine the need for these new regression equations, analysis of covariance (ANCOVA) was used to compare the slope and y-intercepts of regressions from the Terry Collection data and from the data collected from the more modern sources. If the slope for a regression for a specific measurement in the Terry Collection falls in the range of the confidence intervals for the regression of the same measurement in the current data set, then there is no significant difference in the slopes, and no need to update the regression. If there is no significant difference in the slope, then the *y*-intercepts can be tested in the same way to determine if there is a scale difference between the samples.

Table 4.13 covers the ANCOVA results for females. For the regression of the maximum length of the femur onto stature, the slope for the Terry Collection data falls within the confidence intervals of the regression for current research. The slope of the regression line for the maximum length of the femur onto stature from the current research falls within the range of the confidence intervals of the regression from the Terry Collection. These results show that there is no statistically significant difference between the slopes of the regressions. Comparisons of the *y*-intercepts for the two regressions reveal that there are significant differences between the samples of femora in females. ANCOVA of the regressions for the fibula to stature in females indicate a similar pattern with no significant difference in slope, but a significant difference in the *y*-intercepts.

Results from the ANCOVA on the female samples are consistent with the ANOVA results for the same set of data. Stature between the two sets of females is different, and thus so is the *y*-intercept. There was not significant change in the lengths of the femur or fibula, and the slope has not changed significantly.

ANCOVA tests on the male samples displayed in Table 4.14 show significance in the tests of the slopes. Both the slope for the femur and the fibula regressions of the current samples fall outside of the confidence intervals for the regressions of the Terry Collection males, meaning there are significant differences between the samples. The result for the fibula regression fits with the ANOVA results, as there was a significant change in average length of the fibula.

There has been positive allometric change in the upper portion of the body as inferred from the lack of change in the lower limbs according to these results. There are differences in the slopes or *y*-intercepts for all of the groups. Due to the differences, the new stature estimation formulae should be used to provide more accurate results.

6 CONCLUSIONS

The data collected for this research show average statures similar to those found in the National Health and Nutrition Examination Study for similar time periods. While the sample is small, it may not be completely representative. However, the sample does seem to approximate extant populations.

All measurements are significantly different for males and for females, necessitating the separation of the sample by sex, and ultimately creating separate sets of stature estimation formulae. The lack of significant change in the lower limbs of the females when compared to statistically significant change in stature suggests that the location of greatest change is found in the upper body, or trunk. Although there was not marked change in the long bones of the lower limbs, there has been a change in stature that requires the creation of new stature estimation formulae.

These analyses demonstrate that the upper breadth of the femur is moderately correlated with stature in both males and females. This dimension is therefore an easy to replicate measurement that is a reliable alternative to the standard measurement technique in cases where fragmentary femora are the only bones available.

The higher correlations between the upper breadth of the femur and the maximum length of the femur than those between the upper breadth of the femur and stature fail to take into account the need to use a second regression. Further analyses will be completed to test the accuracy of these new formulae.

The research completed herein confirms the significant change in stature in the United States and the need to create new stature estimation formulae that produce more accurate results. New non-race based formulae for males and females were presented. In addition, the upper breadth of the femur was shown to be moderately correlated with stature, allowing it to be used in stature estimation when incomplete femora are present.

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